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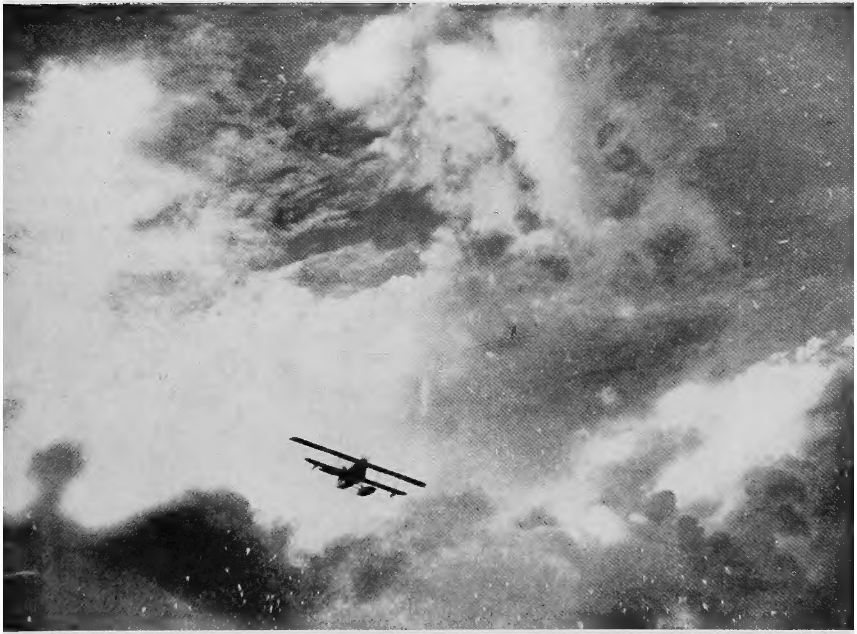

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SEAPLANE FLYING THROUGH CLOUDS.

(925) [*Frontispiece*

PITMAN'S MASTERY SERIES

THE
MASTERY OF AIR

BY THE AUTHOR OF

THE TRIUMPH OF MAN

LONDON
SIR ISAAC PITMAN & SONS, LTD.
PARKER STREET, KINGSWAY, W.C.2
BATH, MELBOURNE, TORONTO, NEW YORK
1922

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PREFACE

THIS little book is one of four on *The Mastery of Earth, The Mastery of Air, The Mastery of Fire,* and *The Mastery of Water.* They take their titles from the " four elements" of the Greek philosophers, and they seek to tell how Man has acquired a " mastery " both in the sense of understanding, and in the sense of using for his own benefit. They offer such scientific explanations as are necessary, supply such history as is desirable, and describe such applications as are appropriate for boys and girls who, born in these later years, enter a world so rich and varied that it compels attention, so complex that it defies analysis.

The author's object has been, in the first instance, to suggest interests rather than to satisfy needs. He has tried to exhibit something of the range of human knowledge and the variety of human activity. He has endeavoured to present science not merely as a subject of the study, but also as a vital force in the field, the factory, and the mine. In a word, he has striven to show how scientific knowledge is blended with imagination and enterprise in promoting the welfare and progress of mankind.

As sources of some of the subject matter the author desires to acknowledge indebtedness to Turner's *The Romance of Modern Aeronautics* (Seeley Service & Co.); Baird's *British Airships, Past, Present and Future* (John Lane); and the *Diving Manual* of Messrs. Siebe, Gorman & Co. The Publishers wish to express their thanks to those who very kindly gave valuable help with the illustration of the book, and in particular to the Air Ministry.

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THE MASTERY OF AIR

CHAPTER I.

When the Wind Blows.

Is it not rather a curious thing that a whole volume—even a small one—should be written about the air in which every one lives ? You cannot move ever so slightly without creating a disturbance in the atmosphere by which you are surrounded ; and you cannot exist for more than a minute or two without taking big draughts of it into your lungs. Men are like crabs crawling about at the bottom of an immense ocean, which extends on all sides, and for perhaps a couple of hundred miles above them. Surely they should know all about such a common everyday thing as air ; yet it has taken them many centuries to find out what they know to-day.

Of course, even primitive men knew there was something all round them which they could not see. They could feel it and see its effects. For there are hot winds and cold winds, light zephyrs that barely stir the leaves on the trees, and violent hurricanes that tear up the giants of the forest and raise the waves of the sea mountain-high. Wherever there are great differences from day to day it is impossible, even for people who do not think much, to avoid noticing them ; and though man had, perhaps, less reason to fear the whirlwind than the flood, he must have been almost as certain that air existed as that water, earth, and fire were important to his well-being. But because air was less liable to harm him, he was slower in finding out all about it, and in harnessing it in his service.

Probably one of the first important applications of air was to the bellows, which is employed to this day for forcing air into the blacksmith's forge. But as this more properly concerns *The Mastery of Fire,* we must look round for some other early example. From the remotest times man realised that corn was nicer to eat without the husk, and some dry leaves blown along by the wind may have given him the idea that if the grain were crushed between two stones the husk might be blown away. For this purpose he would use the bellows which Nature had given him, drawing deep breaths of air into his lungs and expelling it from his mouth.

Now the labour of rubbing the upper over the nether millstone, as well as that of blowing the husk away, would set him thinking how to perform his task more easily. This problem was not solved at once, for two other discoveries had to be made first. One was the use of a sail for driving a boat along the surface of water, and the other was the construction of a water-wheel. The force of the wind is never so steady, nor is its direction so constant, as in the case of running or falling water; but the idea of a wheel to be driven by the wind would certainly follow the invention of the water-wheel sooner or later.

The need for a steady breeze prevents the setting up of windmills just anywhere. In mountainous districts, the wind, blowing hither and thither among the crags, varies continually both in direction and in force. The mountain-side is the home of the waterfall and the water-wheel; the windmill is at its best in flat, open stretches of land, where every tree tells the direction and force of the prevailing aerial currents. In no other

AN OLD DUTCH WINDMILL.

country in the world have windmills been used so freely as in Holland, where they form a prominent feature of every landscape.

An old-fashioned wheel to be driven by the wind is made up of four blades, vanes, or sails, mounted on a central boss and standing out from it like the spokes of a rimless wheel. The sails are all twisted in the same direction, so that when the wind blows in a line with the axis it elbows them out of the way and causes them to spin round. The essential difference between it and a water-wheel will be noticed at once, for in the latter the wheel is set with its axis across the current; and this difference is obviously due to the fact that the water-wheel is only partly, while the windmill-sails are wholly, immersed in the driving current.

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A "DANDO" WINDMILL PUMPING WATER ON A FARM.

Again, as the direction of the flow of water in its channel is constant, the water-wheel can be fixed in position. Not so the sails of the windmill, which must be capable of being turned round to meet every wind that may blow. There are two ways of doing this. In the case of the old German mills, the whole mill could be rotated on a pivot or central post; but in the Dutch mills of the fifteenth century the cap only was mounted on wheels.

The use of steam and electricity, which are regular and certain in their action, has largely driven out a machine which depended upon the fitful wind, but there are still a good many made for work like pumping, which requires to be done only occasionally. Stone, brick, and timber have, however, been replaced by steel. The metal many-bladed wheel is much smaller than the old wooden ones, and it is mounted on a tall, light framework of steel bars. In hot, dry countries, where the surface water is rapidly evaporated by the scorching sun, water can often be obtained from shallow wells, and for this purpose a windmill is frequently used. These modern windmills will work with a small air-current, and they are equipped with a tail, like the tail of a weathercock, which keeps the head to the wind. As often as the wind blows, they spin round and pump water into a trough or reservoir for use in the house or on the farm. Beyond oiling occasionally, they require no attention, but can be left to themselves to draw energy from the passing breeze.

CHAPTER II.

Weighing the Air.

THOUGH the people who lived in ancient times very soon found out how to utilise the wind for propelling their ships, they were very many years in getting to know much about it. They learned, for example, that, if an attempt were made to empty a vessel of air so as to make what is called a vacuum, the air crept in through every available passage; and they said that "Nature abhorred a vacuum." On this principle the Greeks constructed lift-pumps as early as 200 B.C.

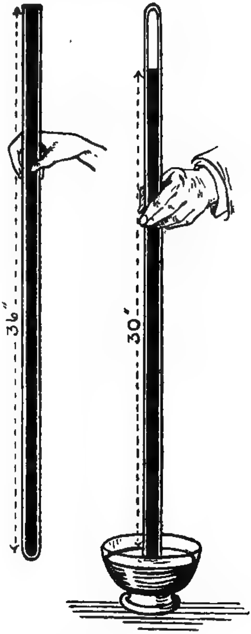
In order to understand the principle of the lift-pump, suppose a long tube to be provided with a tightly-fitting piston or plug, which can be drawn backwards and forwards from end to end of the tube by means of a rod. If the piston is forced to the lower end, and that end is immersed in water, any attempt to draw up the piston results in the water following it up the tube. If the water did not rise the space below the piston would be empty, and as Nature objects to this, said the Greeks, she forces the water up after the piston.

Nearly eighteen hundred years after this discovery had been made, there lived at Padua, in Italy, a wise man named Torricelli. He had been a pupil of the famous Galileo, about whom we learned something in *The Mastery of Earth*, and, like him, he was not prepared to accept without question all that was contained in old books. From time to time he made experiments, and one of them is of such immense importance that you will be interested to hear something about it.

A problem arose in this way. Galileo found that a pump that he possessed would not raise water for more than about thirty feet, and yet the closest examination did not reveal any defect. He talked over the difficulty with Torricelli, who thought a good deal about it and reasoned in this way. Suppose that, instead of rushing in of its own accord to destroy the vacuum, the water is forced up by the pressure of the air on its outside surface. If so, the water will rise only until the weight of the column of water in the tube exactly balances the pressure of the air; therein would lie the explanation of the refusal of Galileo's pump to lift water above a certain height.

It will be understood that an experiment that requires a column of water thirty feet or more in length was not easy, and it occurred to Torricelli that a liquid like mercury, which is about thirteen and a half times as heavy as water, might be used instead. So heavy a liquid, however, requires a strong tube, which must also be of glass, in order that the experimenter may be able to see what takes place inside. For a long time no attempt could be made, but at last, in 1643, a friend of Torricelli's succeeded.

A glass tube about three feet long was closed at one end and completely filled with mercury. The open end was then closed with the finger, the tube was turned upside down, and the lower end immersed in a basin of mercury. On removing the finger, the mercury fell until the top of the column stood at about thirty inches above the level of that in the dish. If the tube was held in a slanting position the upper level of the mercury still remained thirty inches above that in the dish. The height, therefore, was dependent upon something, outside the tube, which did not alter even when the position of the tube was changed.



TORRICELLI'S EXPERIMENT.

The space above the mercury was, as far as could be seen, empty. It looked as though it might be filled with air, and yet no air could have got in without the bubbles being seen as they rose through the mercury. Moreover, if the tube were lowered while remaining quite vertical, the column of mercury filled it when the closed end came within thirty inches of the level of the mercury in the basin. According to the ancient writers, there should never have been any space above the mercury; "Nature," they said, "abhors a vacuum," and will not permit it to exist. But it was quite evident that Nature's objection ceased when the vacuum was formed above a column of mercury thirty inches in height.

Here was a puzzle. The clever men who had written the old books were wrong, and here was a fact of which they were ignorant—one which they would have said could not be. The only possible explanation was that something pressed on the mercury in the dish and forced it up the tube; and the only thing that could have exerted such a pressure was the atmosphere.

Up to this time men did not know how far the atmosphere extended—whether it was merely a layer round the earth, or spread throughout the whole of space. But Torricelli saw that the atmosphere must be a layer, and that it must exert a pressure, due to its weight, upon every portion of the earth's surface, and he showed how this pressure could be measured.

Suppose the sectional area of the tube is 1 square inch, then the volume of the mercury in the column is 30 cubic inches. The weight of 1 cubic foot of water is 62·4 lb. nearly, so that the weight of 30 cubic inches would be—

$$\frac{30 \times 62{\cdot}4}{1728} = 1{\cdot}08 \text{ lb.}$$

And as mercury weighs 13·6 times as heavy as an equal bulk of water, the weight of 30 cubic inches of mercury would be—

$$1{\cdot}08 \times 13{\cdot}6 = 14{\cdot}7 \text{ lb. very nearly.}$$

If the reader is of a critical turn of mind he will probably ask: "Why does this measure the pressure on the surface of the mercury?" The scientific answer is, "Because liquids (and gases, too) exert pressure equally in all directions." You cannot apply pressure at any

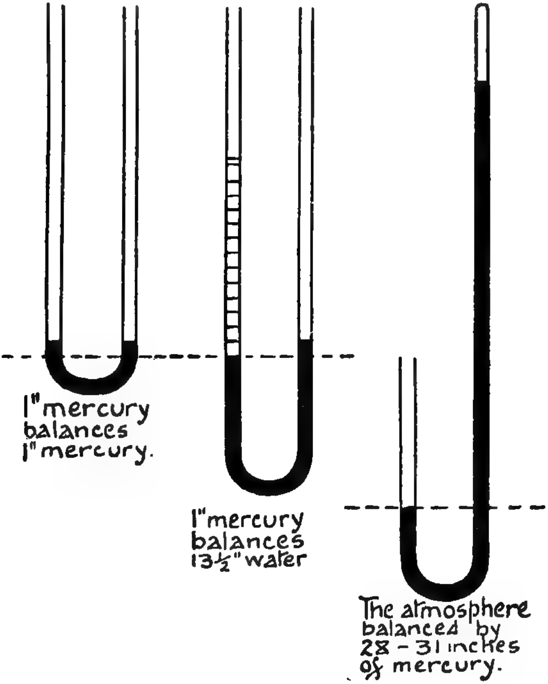

1" mercury balances 1" mercury.
1" mercury balances 13½" water
The atmosphere balanced by 28 - 31 inches of mercury.

DIAGRAM EXPLAINING THE PRINCIPLES OF THE BAROMETER.

point of a mass of gas or liquid without that pressure being felt in every other part. Moreover, the pressure at any level in a liquid must be the same all through it. For if it were greater at one spot than at another, the liquid would immediately flow from the region of high pressure to the region of low pressure until the pressures in the two regions were equal. It is for this reason that the free surface of a liquid at rest is always level.

Now, owing to the fact that fluids transmit pressure equally in all directions, not only the earth's surface, but the surface of everybody and everything, living or lifeless, is subject to the same pressure. There is a great number of interesting experiments to illustrate the "crushing effect of atmospheric pressure," as it is called, one of which may be described here Knock a hole through the lid of a coffee tin, and solder over it a neck of brass tubing, or a tin ring, about half-an-inch in diameter. Then solder the lid all round, and see that it is water-tight at all the other joints. Pour a little water into the tin, and set it over a lamp or gas flame until it boils vigorously. Remove it, cork the hole up tightly, and throw the whole thing into a bucket of water. You will find that the tin immediately crumples up. The steam from the boiling water has driven out the air, and has been converted into water again by cooling. The steam occupies nearly 1,700 times the volume of the water from which it is derived, so that when it is condensed a vacuum is formed, and the pressure of the atmosphere outside crushes the tin in.

Suppose the tin is six inches deep and three inches in diameter. The area of its curved surface is—

$$\frac{22}{7} \times 3 \times 6 = \frac{396}{7} \text{ sq. in.,}$$

and the area of the ends is—

$$\frac{22}{7} \times \frac{3}{2} \times \frac{3}{2} \times 2 = \frac{99}{7} \text{ sq. in.;}$$

so that the total area is—

$$\frac{396}{7} + \frac{99}{7} = 70{\cdot}7 \text{ sq. in.},$$

and the total pressure on the tin is—

$$70{\cdot}7 \times 14{\cdot}7 = 1{,}040 \text{ lb. very nearly},$$

that is, not far short of half a ton. No wonder it crumples up!

The properties of a vacuum excited no little interest at the time; and, if possible, it becomes more wonderful the more one knows about it. The fact that merely looking at it does not enable you to say whether air is present or not shows that it allows light to pass through it. As most experiments require the use of an air pump which will be described in a later chapter, only two more experiments will be described at this stage. A strong glass tube, closed at one end, has a little water poured into it. The water is then boiled, and when steam is issuing freely from the open end (which has previously been drawn out to a fine tube) the tube is sealed up by melting it in a flame. The tube now contains water in a vacuum. If it be inverted quickly the water falls in a "lump," making a sharp metallic "click" as it reaches the bottom.

If the tube had contained air the water would have been impeded in its fall, and would have made, at most, a faint splash. But in the absence of air the whole of the water falls at once, striking the bottom suddenly and causing the sound which has earned for the instrument the name of "water-hammer."

The effect of air in impeding the motion of falling bodies is well illustrated by the famous "guinea and feather" experiment which used to be shown far more often than it is now. You know that if a small, heavy object, such as a guinea or a sovereign, is allowed to fall, it drops to the ground in a straight line, while, if a feather is held up and then released, it floats about and comes to earth, it may be, yards away from the point immediately below. In any case, it occupies far more time in reaching the ground. But if the two objects are held on a small platform or shelf at the top of a tall and wide glass tube from which the air has been pumped, and if the platform is then tipped so that they are both released at the same instant, they will be seen to fall to the bottom together. When the resistance which the air offers to the motion of the feather is removed, both feather and guinea fall, according to the law of gravitation, through the same distance in the same time.

To go back now to the column of mercury in the tube. Torricelli saw at once that it would enable men to detect any variation in the weight of the atmosphere; and he saw, too, that variations in the weight of the atmosphere at different places would lead to differences of pressure which would cause winds. Since cold air is heavier, bulk for bulk, than warm air, it follows that, in general, the column of mercury is higher on a cold than on a hot day. Again, since water vapour is lighter than air, it follows that air saturated with water vapour is, bulk for bulk, lighter than dry air, and so the height will be greater in dry weather than in wet weather. The Torricellian instrument is called a barometer, and, as you probably know, it is used to indicate a change in the weather even before that change occurs.

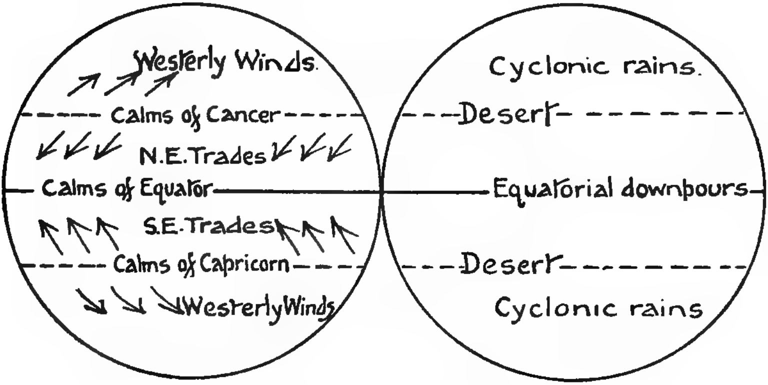
For example, if the air is dry, and the barometer correspondingly high, there is not likely to be rain, because rain falls only when the atmosphere is overcharged with moisture. On the other hand, if the air is moist it will be light in weight ; and so the barometer will be " low " when rain may be expected.

Every daily paper, nowadays, contains a statement as to the weather likely to be experienced during the next twenty-four hours. The forecast is made by examining a chart upon which have been marked the heights of the barometer at a number of different places, these " readings " having been sent to the Meteorological Office in London by telegram. Observation of the chart for several successive days will show that there are certain regions of low pressure which are moving in definite directions ; and, from the rate of movement, a rough idea can be obtained as to the time at which they will reach any particular place. These moving areas of low pressure carry rain or, in cold weather, snow, with them.

Forecasts like this are not certain, because sometimes violent changes of pressure occur with very little warning. The atmosphere is in continual commotion, and no one can tell when a depression will arise, or where it will die out. In the tropics more especially the changes occur with a suddenness that defies man's guesses, and terrible hurricanes arise which sweep with irresistible force across land and sea.

But this is taking us into the question of winds, which in themselves form a large and fascinating study. The early navigators learned that in certain parts of the earth the air currents are constant in direction throughout the year, and in other parts they blow steadily in a definite direction according to the season. Winds of the first class are due to two main causes—the rotation of the earth and the heat of the sun. As the earth turns on its axis, the air lags behind, especially at the Equator, where the velocity of the surface is greater than elsewhere.

This, acting alone, creates a wind in the direction opposite to that in which the earth is moving. Again, the heat of the sun warms the air to a greater extent at the Equator than elsewhere, and as this hot air rises, cool air flows along the earth's surface from the northern and southern hemispheres to take its place. The result is that, instead of a wind parallel to the Equator, there are two sets of air currents, blowing from the north-east in the northern hemisphere, and from the south-east in the southern. These are called the North-East and South-East Trades, because they were so important to merchantmen in the days of sailing ships.



MONSOON AND TRADE WINDS.

The second kind of wind is due to the different behaviour of land and water towards heat. To raise a pound of water through any range of temperature, or degree of hotness, about twice as much heat is required as to do so to a pound of earth. Under the influence of the sun, therefore, the water rises in temperature much more slowly than the land. For the same reason the temperature of the land falls more rapidly than that of water. This effect is perhaps more important in Southern Asia than in any other part of the globe.

During the hot Indian summer the land becomes highly heated, and heats the air in contact with it. The hot air rises, and cooler air flows in from the ocean, bringing with it vast quantities of moisture, upon which Indian agriculture depends. But, during the cooler season, the land loses its heat more rapidly than the water; the air over the water rises, and fresh air flows in from the land to take its place. The parts of the earth in which this occurs are called monsoon regions, because the moist wind is known as the monsoon. The strength and wetness of the monsoon vary, and, before the Government of India undertook the storage of water for the crops, there was sometimes plenty and sometimes famine in the land.

Winds of exactly similar cause, but on a smaller scale, are the land and sea breezes, which are familiar to all who live at the seaside. During the day the land becomes hot, and a cool wind sets in from the sea. When the sun has set, the land cools quickly, and a land breeze arises which blows in the opposite direction.

All these winds are peaceful, harmless movements of the ocean of air, of which man takes full advantage, either in his seaborne trade, or in his agricultural operations. But there are others, which, having their origin in some slight disturbances, gradually gain in violence until they sweep all before them. These are called cyclones, because of the whirling motion of the air currents. This whirling motion is always in the direction of the hands of a watch in the northern hemisphere, and in the opposite direction in the southern hemisphere.

A cyclone appears at first as a small cloud on the horizon, which gradually increases in size until it seems to fill the sky. But its approach is indicated, long before it can be seen, by a sudden fall in the barometer.

The cyclone is a terrible foe to-day, and was rightly dreaded by those in sailing-ships. Anxiously the captain would keep his glasses riveted upon the advancing storm, and endeavour to shape his course so as to avoid it. If that was impossible, then the helm was set so that the storm would have the least effect. The first shock often tore the sails to ribbons, and caused the vessel to heel over as though to bury herself beneath the waves. The masts bent, and not infrequently snapped off as though they were mere sticks. Men were washed overboard, and the decks were swept clear of every movable fitting. But in these fierce fights with Nature man was mostly victorious, and refused to be driven from the seas.

So far we have only considered the causes and results of an alteration of the barometric height at one level—that of the sea. But it was seen at once that there was another cause of variation. When the news of Torricelli's experiment reached Paris, Pascal, a famous Frenchman, pointed out that there would probably be a smaller thickness of air at the top of a high mountain than over land at the sea level. If this were so, then the pressure would be less, and the column of mercury it would support would not be so high. Thus, at a height of 5,000 feet, the barometer stands at only 25 inches; at a height of 10,000 feet at only 20 inches; on the top of Mount Everest, or at a height of about 29,000 feet, the column would be less than 11 inches; and so on.

This fact enables the measurement of altitude, whether of a mountain or of a balloon, to be made in the simplest possible way. It has even been employed to obtain information about the atmosphere at altitudes so great that a man could not live in them. Each draught of air which he took into his lungs would contain too little oxygen to support life, and the rarity of the air would cause the small, and but slightly protected, veins of the mouth, nose, and ears, to burst. The plan has been to send up kites and free balloons, carrying self-registering barometers and thermometers, the records of which could be examined when the kite or balloon returned to earth.

Among other discoveries, it has been found that the upper regions of the atmosphere are intensely cold, and must, therefore, be intensely dry; for the colder the air becomes the less moisture it will hold. You know that even in the Tropics the highest mountains are always covered with snow. The height above which snow never melts completely, but remains as a mantle of white all the year round, varies with the latitude, and the line joining these heights, from the Equator to the Poles, is called the "Snow-line." It is no more than 16,000 feet at the Equator, and becomes less as the distance from this region increases. The free balloon soars far above this height, though a kite has not risen higher than about 3½ miles. Free balloons have risen to 12 miles, and at the height of 6 miles the temperature was found to be nearly 60°C *below* the freezing-point of water. Thus it is clear that the heat of the sun passes through dry air without raising the temperature. It is water vapour in the air that absorbs heat rays and causes the air to become warm.

There are several interesting facts of everyday life which depend upon the power of water vapour to catch and imprison heat. Thus, the nights are colder when there is a clear sky and the earth can radiate into space, unchecked, the heat which it has received from the sun.

On these occasions, the air in contact with the ground becomes cooled and deposits its moisture in sparkling drops of dew on every leaf and blade of grass. If the temperature is very low, then hoar-frost takes the place of dew, and the morning sun reveals a scene of splendour which can hardly be surpassed. Every tree and shrub, every plant, even the delicate embroidery of moss, is clothed in glistening crystals of ice, and the commonest object becomes a miracle of beauty. But on cloudy nights the warmth of the earth is trapped and the temperature is rarely so low as when the stars can be seen like jewels set in the black velvet of the sky.

Writing on this subject many years ago, John Tyndall said: Water vapour is a blanket more necessary to the vegetable life of England than clothing is to a man. Remove for a single summer night the aqueous vapour which exists in the atmosphere, and you will most assuredly destroy every living thing that is capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself, unrequited, into space, and the sun would rise on an island held fast in the iron grip of frost.

This beneficial water vapour exists, as we have seen, only in the lower layers. The upper regions even only three or four miles above the surface, are dry and cold. At a height of twelve miles, the air is so thin and its pressure so small that it can hardly be measured by the barometer. But there is evidence that it extends far higher than this—probably as far as 200 miles above sea-level. One piece of evidence of this is obtained from shooting stars. There are, flying through space with enormous velocity, and along definite paths, lumps of material composed of the same substances as are found in the earth's crust. These bodies are called "meteorites," and when they enter the earth's atmosphere, the friction causes them to become hot and luminous. The smaller ones are fused and even turned into gas, but the larger ones are only partly fused and reach the ground, into which they sometimes burrow for several feet.

If we glance up into the sky, it seems to us that they belong to the starry world; but in reality they are visible only after they have entered the atmosphere. The measurement of their height when they first appear gives a clue to the height of the ocean of air above our heads.

CHAPTER III.

Air Pumps.

SUPPOSE you have a cylinder closed at one end by a tap, as represented in the illustration (p. 20). Let the piston be pushed in until it occupies the position shown, and then let the tap be closed. If the piston is now drawn back towards the open end of the tube, the air inside expands continuously, completely filling the space between the piston and the closed end. This reveals the principle on which the Suction Air Pump works.

The action will be clear from the figure. At each outward stroke the space between the piston and the valve is increased, and the pressure of the air in this, therefore, falls below that of the air in the bell-jar. Air immediately flows from the bell-jar, through the valve and into the barrel, until the pressure is the same throughout. As soon as the piston starts to come back again, the valve closes, and when the returning piston has caused the pressure in the barrel to rise higher than that of the atmosphere, the outlet valve opens and permits the air to escape. This process is repeated with every stroke of the pump, a small quantity of air escaping every time from the bell-jar, or receiver, as it is sometimes called. The difference between the pressure of the air in the receiver and that of the air in the barrel with the piston drawn out finally becomes so small that it will not lift the valve.

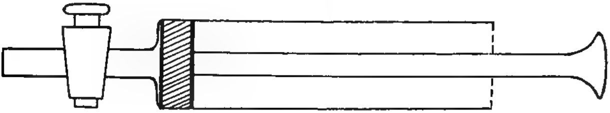


DIAGRAM SHOWING PRINCIPLE OF SUCTION AIR PUMP.

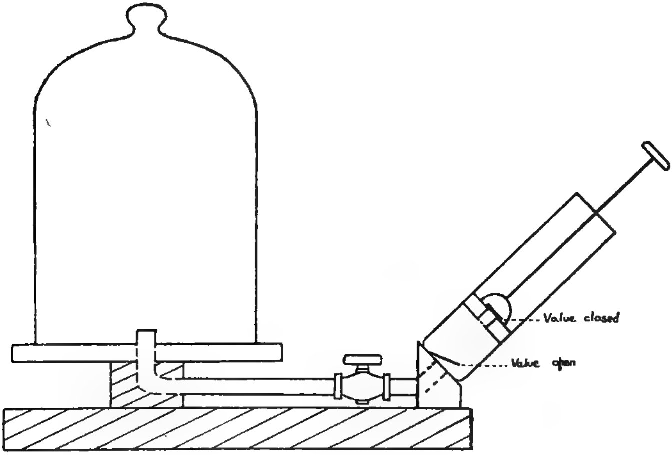
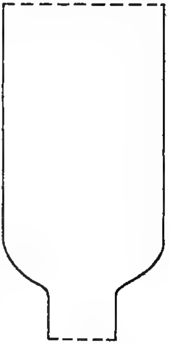


DIAGRAM OF AN AIR PUMP.

The extent to which a pump of this kind will remove the air from the receiver depends partly upon the lightness and tightness of the valve, and partly upon the ability of the piston to sweep the whole of the air out of the barrel on each downward stroke. In both these respects, the Fleuss Pump, which need not be described in detail here, is superior to the older form. But even one of simple form will exhaust a glass vessel so that, unless it is very strong, it will collapse under the pressure of the atmosphere. This may be shown by using a receiver open at both ends, as in the illustration, covering the top with a piece of window glass. With a receiver four inches in diameter 15-oz. glass may be used, but with one eight inches in diameter even 21-oz. glass will be broken after a few strokes of the pump.



A RECEIVER OPEN AT BOTH ENDS.

It is always interesting to get numerical values of the results of such an experiment. Suppose the volume of the barrel is 20 cubic inches, and that of the receiver 500 cubic inches. Let the piston, or plunger, be at the lowest point of its stroke. Then, after the first upward stroke of the plunger the 500 cubic inches of air in the receiver will occupy 520 cubic inches, so that there will be only $\frac{500}{520}$ of the original amount of air remaining in the receiver when the valve closes. This, of course, fills the whole receiver; that is, it has still a volume of 500 cubic inches, although its mass, weight, and density have been reduced.

The next upward stroke of the piston will cause this to expand again from 500 to 520 cubic inches, and the quantity remaining in the receiver after the following downstroke will be only $\frac{500}{520}$ of $\frac{500}{520}$ of the original amount. This may be written shortly: $(\frac{500}{520})^2$ of the original amount.

In a similar way, it becomes clear that the quantity remaining at the end of the third stroke will be $(\frac{500}{520})^3$, and at the end of the fourth stroke, $(\frac{500}{520})^4$ of the original amount.

If n strokes are made, the mass of the air left in the receiver will be $(\frac{500}{520})^n$ of what it was at first.

Since 500 represents the volume of the receiver and 20 the volume of the barrel, we can easily make a general formula for the calculation. Calling the first V, and the second v, the quantity remaining after n strokes is $\left(\frac{V}{V+v}\right)^n$ of what it was originally; and under ordinary atmospheric pressure, the space it would fill is only $\left(\frac{V}{V+v}\right)^n \times V$ cubic inches.

Let us suppose that the pump has been worked until there is only half the original quantity of air in the receiver. The pressure under the glass plate is now only half of the ordinary pressure; that is, as this is about 15 lb. on the square inch, there is an excess of 7½ lb. on the square inch acting downwards. As a plate eight inches in diameter has an area of about 50¼ square inches, the total excess of pressure is about 377 lb. If the whole of the air were removed, the pressure would be about 754 lb., or over ⅓ of a ton.

The pump which we have described depends upon the tendency of the air to expand and fill all the space open to it. There is another very beautiful way of using this property so as to construct an air-pump. If mercury, or quicksilver, is allowed to flow slowly through a tube, as in the diagram, the thread of silvery metal breaks off at the top of the bend in short lengths. These follow one another at short intervals; and, clearly, each space between the threads of mercury must be a vacuum.

Now, as each space passes the end of the side tube, air enters, and is carried down between the successive threads. This side tube can be connected with any vessel that is to be emptied of air or any other gas it may contain; and, so long as the mercury falls or any gas remains, small bubbles are trapped and removed with never-failing regularity.

Such pumps are called Mercury Pumps, and different forms of them are called after Geissler, Sprengel, and other men who devised them. Apart from their use in scientific experiments, they are extensively employed in the manufacture of electric glow-lamps. The filament is first fixed in the bulb, and then the little tube, drawn out very finely and remaining at the other end of the bulb, is attached to a mercury pump; after sufficient air has been removed, or, in other words, when the vacuum is high enough, this little tube is sealed up, leaving only a small point on the bulb. As only the faintest trace of air remains in the bulb, and the area of surface is probably more than twenty square inches, the atmosphere exerts a total crushing force on it of something like 300 lb.

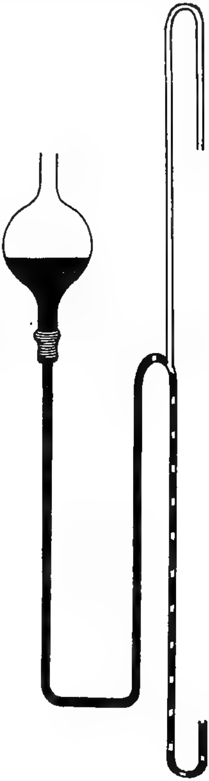


DIAGRAM OF A MERCURIAL VACUUM PUMP.

If a very high vacuum is not required, the most effective method of obtaining it is by means of a water-jet.

Set up a piece of glass tubing, *A*, as shown in the sketch, with its lower end dipping into water, and then blow across the top of it with another tube, *B*, which has been narrowed down at the end. The water will immediately rise in the tube *A*, and, entering the jet of air, will be broken up into a spray. The explanation is quite simple. A jet of liquid or gas, moving with a high velocity, drags along the air in contact with it, causing a partial vacuum in its neighbourhood. Fresh air, including that in the tube, rushes in to take the place of that dragged away, and the water is forced up the tube by the pressure of the atmosphere.

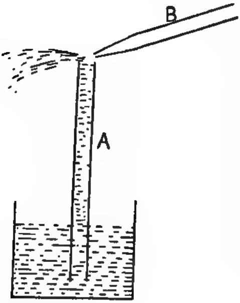
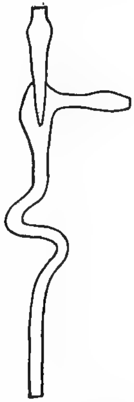


DIAGRAM OF A WATER JET.

The barber's spraying apparatus is often based on this principle; and so also is the apparatus for spraying plants and fruit trees, to kill, or to prevent attack by insects. For a large piece of apparatus a pump is used; but for a small one a rubber ball, fitted with a valve which opens only inwards, is sufficient. When the ball is squeezed the air is forced through the tube, and when it is released the valve opens and admits fresh air. To smooth out the jerks and make the spray continuous, a second rubber ball is used between the main bulb and the jet. This expands when the main bulb is squeezed, and contracts when the pressure is released; the main bulb in this case requires two valves, one inlet and one outlet.

But to return to the jet pump. A simple form, made either of glass or of metal, is shown on the opposite page. Water enters at the top, and, in issuing from the narrow end of the tube, causes a partial vacuum, so that air is withdrawn from any vessel connected with the side tube. The chief use of such a pump is to hurry up the process of filtering in laboratories. Filtration consists in separating solid particles from a liquid, and depends upon the fact that water and other liquids will pass through the pores of paper, asbestos, etc., more readily than the particles of the solid will. The paper used is specially made for the purpose and is very much like blotting paper in appearance and texture. It is folded so as to fit inside a funnel ; the muddy liquid is poured in, and the clear liquid runs through. By forming a partial vacuum below the funnel, the pressure of the air on the surface forces the liquid through more rapidly.



A SIMPLE JET PUMP.

Suction air-pumps are used on a large scale for distillation in many manufacturing processes. Liquids that dissolve very readily in each other often have very different boiling-points, and, when the temperature of the solution is raised, the liquid of lower boiling-point comes off first. A little of the liquid of higher boiling-point also comes over as well, especially if the boiling-points are not far apart ; but the process can be repeated several times and a more perfect separation can thus be secured.

Now, the temperature at which any liquid boils depends upon the pressure : if the pressure is reduced the liquid boils at a lower temperature, and vice versa. And as some liquids which are purified by distillation—glycerine, for example—decompose at the boiling-point under ordinary pressure, it is necessary to perform the operation in closed vessels, and to pump away a portion of the air. This is called distilling in a vacuum, and is a very important industrial process.

There is another very important use of vacuum pumps in the creosoting of timber. In this process it is sought to fill the pores of the timber with creosote oil, which is obtained from coal-tar and prevents decay. The timber is placed in a large iron vessel and all the air is pumped out. Then the creosote oil is forced in under pressure. In this way the oil penetrates into the pores of the wood, and renders it more durable than it was before.

Enough has been said to show something of the importance of pumps for removing air, and we may turn to consider those used for forcing air into a vessel. And here we must note at once a difference between air and water. Water is practicably incompressible. An enormous pressure reduces its volume by an amount that is hardly measurable. Air, on the other hand, yields continuously under pressure, so that a very large quantity measured under ordinary conditions can be forced into a very small space. Both air and water are, however, perfectly elastic—if the pressure goes back to what it was originally, the volume also becomes the same. So long as the temperature does not alter, the volume is governed entirely by the pressure.

This difference in compressibility has an important influence on the danger which accompanies a burst. As soon as a gas under high pressure is liberated in this way, it expands right down to the pressure of the atmosphere, and the broken fragments of the pipe or vessel in which it was confined are flung in all directions with great violence. But high pressure water is altered so little in volume that the tube or vessel merely falls to pieces, and any damage which may result is due entirely to the rush of water itself.

One of the earliest and simplest forms of air-pumps was the water-blower, used in the manufacture of iron for driving air into a blast furnace. A jet of water, fed from a mountain stream, was delivered into a tank as shown in the illustration. Air was dragged in by the jet, and as the overflow at the bottom was always covered by water the only escape for the incoming air was through the furnace. This is, of course, a simple modification of the water suction-pump already described.

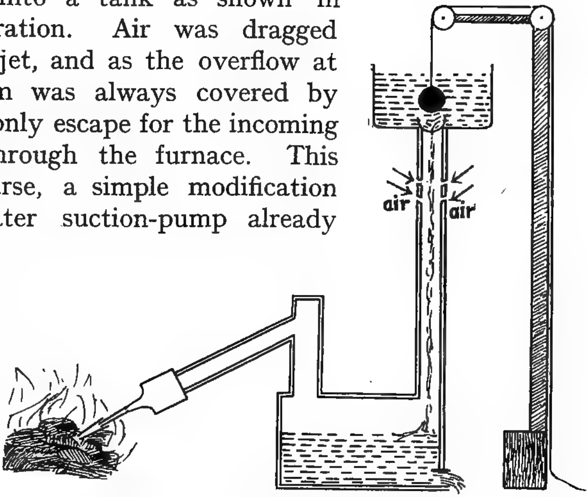


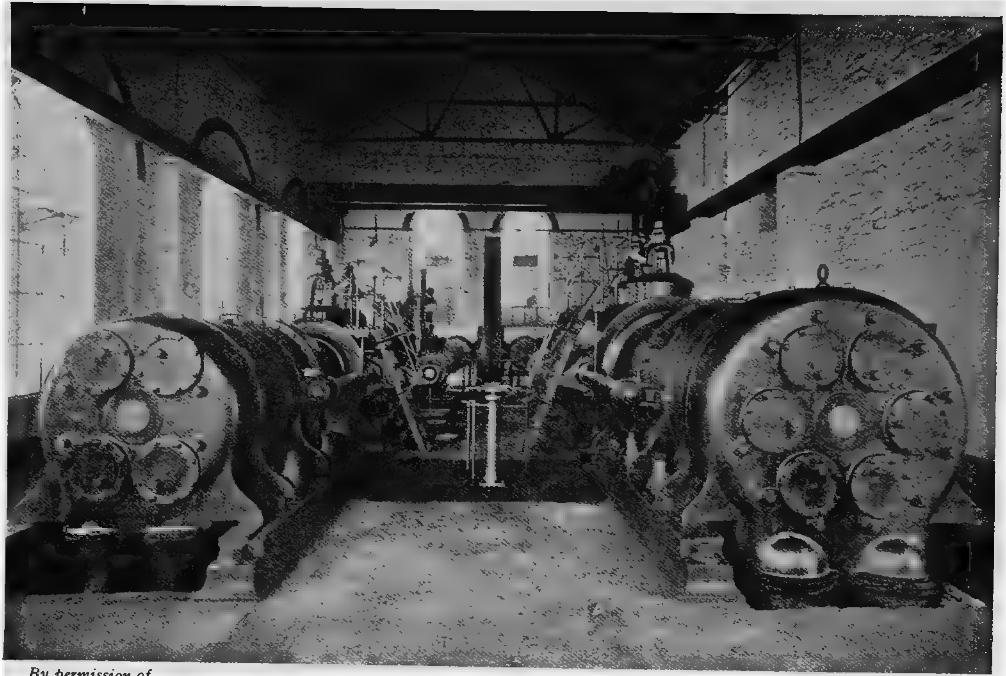
DIAGRAM OF A WATER-BLOWER.

Plunger pumps for compressing air, or "air-compressors," as they are called, are very similar to the pumps used for high pressure water, but the clearance, or space between the piston and the ends of the barrel, is reduced to the smallest possible amount. If even a small quantity of air remains after each stroke, it is alternately expanded and compressed as the piston moves backwards and forwards, and work is thus done on air which never leaves the cylinder. It is necessary, therefore, to avoid the source of waste as far as possible.

When very high pressures, amounting to as much as 1,000 lb. on the square inch, are required, the process is carried on in two or three stages. There are two or three pumps in a row worked from the same crank-shaft, or sometimes mounted round a single crank with the barrels pointing outwards. One pump raises the pressure to, say, 300 or 400 lb. per square inch, and then delivers this air to the second pump, which raises the pressure to, say, 700 lb. per square inch. A third pump receives the air at this pressure and raises it to 1,000 lb. per square inch. In this way the push and pull on the plunger is reduced to one-third of the amount which would arise if the compression was completed in one stage, and the moving parts of the pump are kept lighter than would otherwise be necessary.

For supplying air at moderate pressures there is nothing better than a fan or centrifugal air-pump, very similar to the centrifugal water-pumps mentioned in the volume on *The Mastery of Water*. They are called " Rotary Air-compressors." There is also a very peculiar form known as a " Root's Blower," used for supplying air to blast furnaces. The diagram on page 30 shows a section across one of these. There are two shafts running right through an oval casing, and rotating at high speed in opposite directions. On each shaft is fitted a closed box, in section like a double fan. As the shafts rotate, these fans sweep air from the top, where it enters, round the sides to the bottom, where it leaves. As a fan on one shaft fits in between the two fans on the other shaft, no air passes through the centre. When at work they create an intolerable noise, but they are very effective for their purpose.

Once air is compressed it can be transmitted a great distance by means of pipes, and then used to drive

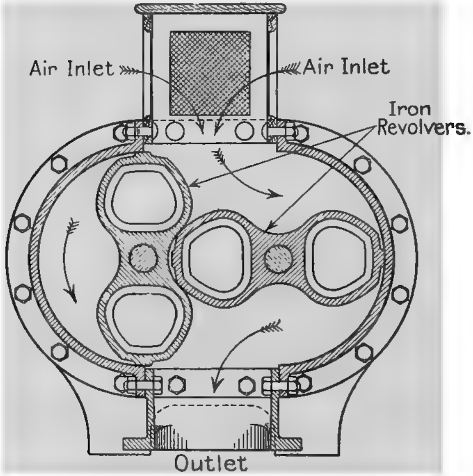


By permission of Walker Bros., Wigan.

LARGE HORIZONTAL AIR COMPRESSOR.

The principle of working is similar to that of a bicycle pump, the air being taken in at one end of the cylinder through a set of automatic valves and pushed out; the plunger is worked by steam.

machines in exactly the same way as steam. You may have read in *The Mastery of Earth* how the great railway tunnels through the Alps were carved out by the aid of rock-drills driven by compressed air. These drills bored holes in the rock, into which gunpowder, and, in later years, dynamite, was placed and exploded. The air, which escaped after doing its work in the drill, helped in the ventilation of the tunnel. Similar rock drills are used in mines; on the Witwatersrand Goldfield, in South Africa, the compressed air flows through 18 miles of pipes from the air compressors to the mines.



ROOT'S BLOWER.

Another important use is found in coal mines, especially in fiery mines in which there is danger of explosion. The cold compressed air expands in passing through the engine, and not only lowers the temperature but helps to reduce the percentage of inflammable gas in the mine by the addition of pure air. Drills are used for boring the holes in which the explosive is placed for blasting, or "shot-firing" as it is usually called, but the most interesting machines are the coal-cutters. Their purpose is to make a horizontal cut at the base of the coal-seam so that it is more easily ripped out by the miner's pick. Some of them have a horizontal wheel with teeth on the edge, like a circular saw which lies flat, only a few inches from the ground. Perhaps the most remarkable one is that invented by Mr. Austen Hopkinson, which consists of a chain carrying cutters on the links. This rotates round two wheels laid flat in the same way as the circular saw arrangement mentioned above. The back wheel is driven by an electric motor or compressed air engine, and the whole machine is pushed up to the coal face. The chain rips out a narrow horizontal slit as it passes round the front wheel.

Every shipyard has a perfect network of pipes conveying compressed air for use in "pneumatic" tools. These are little machines that can be held in the hand and used for drilling, riveting, hammering, chipping, in all sorts of positions in which it would be difficult for a man to use a tool in the ordinary way. The air is led to the tool through a flexible tube protected by steel wire, or armoured, and to stop or start the apparatus the workman has simply to press a trigger (see page 33).

Upon pressing the trigger compressed air enters at A and passes to B and C. From B it flows between the cupped valve V and the piston P and forces the latter rapidly down. Meanwhile some of the air at the back of V escapes through D, so that only a low pressure exists behind the valve which is held back by full live air behind the piston. Free air in front of the piston is not trapped as it escapes out of K *via* the valve groove to exhaust

H. As soon as the piston P passes the main exhaust E in the cylinder and strikes the chisel J, all the air behind the piston escapes so that the low pressure behind the valve V pushes the latter forward.

FIG. 2.—Live air now passes from F round the valve groove to the long hole K and so to the front of the piston P, driving it back to the valve. The continual pressure behind the valve is still further reduced by the small hole G, which is now open so that the piston coming rapidly back cushions the trapped atmospheric air between itself and the valve, and forces the valve back again.

This hammer weighs 10 lb. and strikes from 2,000 to 3,000 blows per minute. It is used for cutting metal, trimming castings, making boiler joints tight and for many other purposes.

Suppose an eighth of an inch has to be removed from one edge of a steel plate, one inch in thickness, for a length of six feet. Half a mile away there is a steam or gas or oil engine, or an electric motor, driving air through pipes at a pressure of 750 lb. on the square inch. The workman at the ship takes up a pneumatic chipper, connects the flexible pipe to the compressed air main, scrambles up to the plate, and presenting the chisel to the edge of the plate, presses the trigger. Immediately there is a furious tapping, the chisel delivering something like 2,000 blows a minute. The metal peels off in curly shavings, and, in not much more time than is required to write it down, the job is done. Pneumatic tools have reduced by nearly one-half the time required to build a ship or a bridge.

The torpedo, one of the most terrible weapons of naval warfare, is entirely dependent upon compressed air. It consists of a steel casing shaped like a fish, 16 or 21

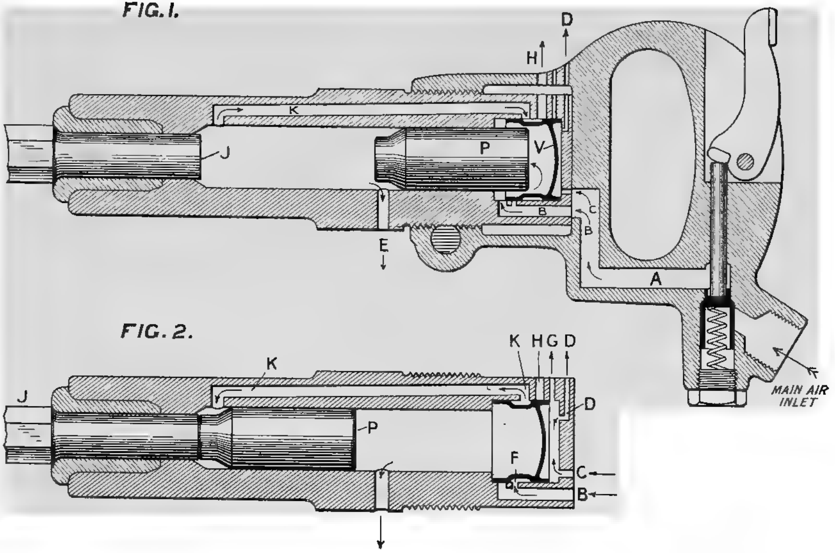


FIG. 1.

FIG. 2.

By permission of *The Globe Pneumatic Engineering Co., Ltd.*

GLOBE PNEUMATIC HAMMER.

feet long and 18 or 21 inches in diameter. At the nose is a sliding rod, and just behind this is a compartment containing about 300 lb. of gun-cotton. When the nose strikes any object, this rod is driven in and causes the gun-cotton to explode with terrible violence. The compartment immediately behind the charge contains a quantity of compressed air in steel bottles, an engine capable of being driven by compressed air, and mechanical devices for keeping the torpedo on a straight course. At the back are two propellers and rudders for steering.

The torpedo is fired from a kind of gun which, on a battleship or other large vessel, is fitted below the water-line. The gun (or torpedo-tube) is fixed in the side of the ship, the opening being covered by a hinged door which is ordinarily kept shut. The torpedo is placed in the tube through a door at the back or side. This is closed, the front door is opened, and the torpedo is forced out in the direction of the vessel which it is intended to destroy. As soon as it leaves the tube the torpedo sets off on its own account, for a valve opens and admits compressed air to the engine which drives the propellers.

A great increase of range and speed has been obtained in recent years by heating the air on its way to the engine. This is effected by a small flame which lights up of itself or " automatically " as soon as the torpedo starts. As a much smaller quantity of hot air than of cold air is needed to drive the engine, the torpedo travels farther from the parent ship. The range is about 7,000 yards, and the average speed for this distance is 27 knots.

There is a number of interesting features about a torpedo which space will not permit us to deal with. It is easy to realise what a menace it is to the crew of a

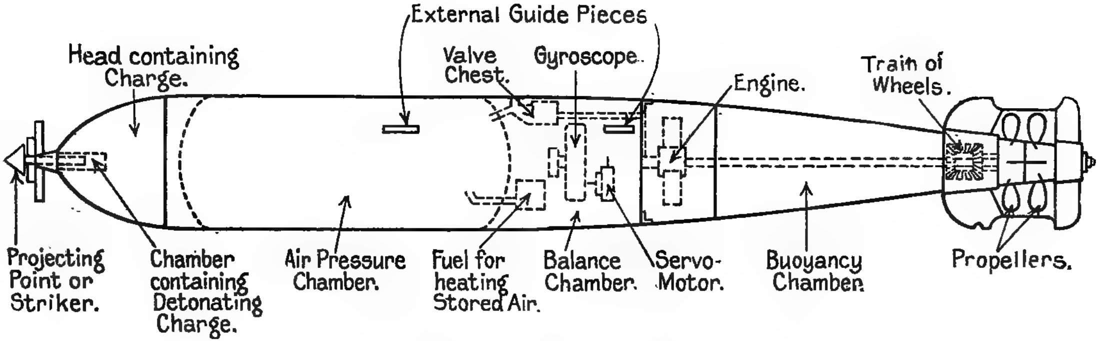


DIAGRAM OF A TORPEDO.

ship, who cannot see it coming to attack them; for it speeds along fifteen or sixteen feet below the surface, and when it strikes is able to tear a hole from fifteen to twenty square yards in area in the ship's bottom.

A very interesting application of air pressure is what is known as "pneumatic dispatch." You have probably been to the post office and handed in a telegram. When this has been duly stamped, it has been placed in a small box, the box has been inserted in a tube, and a lever has been moved sharply a few times. Your telegram has actually been blown through a tube into the room in which the operators are at work. A similar plan is often used in large stores to dispatch the money and bill to the pay desk.

But a much larger system was established in London many years ago by the British Post Office. In the early days of the telegraph there were lines only from the main office. Telegrams were therefore accepted at certain branch offices and sent in pneumatic tubes of about two and a half inches diameter to the central office. Two methods were tried, one by pumping out the air in front of the carriages, and the other by forcing it behind, and the latter was found to be the more effective method. Encouraged by this success the authorities laid a large tube from Euston to the General Post Office. This was ⌓-shaped, four feet six inches wide and four feet high. Rails were laid along the bottom, and parcels are conveyed in carriages which nearly fill the tube. At the back of each carriage is a stiff sheet of rubber which fits the tube. The air in front of the carriages is pumped out, and, though the gradient in some places is 1 in 14, loads of ten tons are forced along merely by atmospheric pressure.

Very many train signals are worked by compressed air. In one system the whole process of raising and lowering the signal-arm is performed by air at about 15 lb. on the square inch. In another system compressed air at 65 lb. on the square inch is used only to move the signal-arm, while the valves are opened and closed by electricity. In the latter case the labour of moving the great lengths of iron rods is avoided.

The train itself is brought to a standstill by pneumatic brakes. On most steam railways in Great Britain the Vacuum Automatic Brake is used, but electric railways have generally adopted the Westinghouse Automatic Brake, which acts by means of compressed air.

CHAPTER IV.

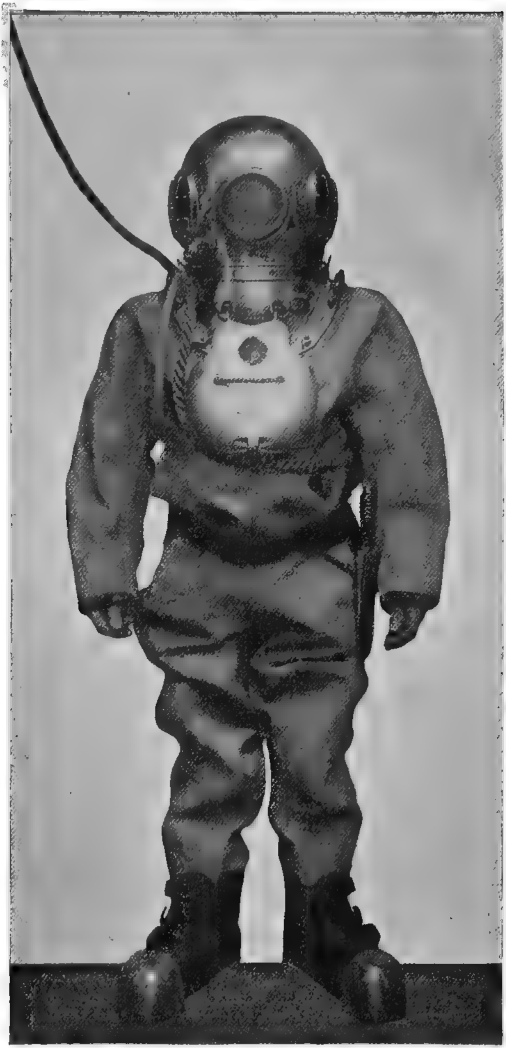
Diving.

FAR away back in the mists of antiquity men learned how the water would bear them upon its surface, and took a keen delight in diving into its depths, with full confidence that they would come up again. As these early submarine explorers went down into the clear waters with their eyes open, they realised that there were treasures on the sea bottom almost equal to those on dry land. In time they acquired endurance and skill, which enabled them to turn their art to useful account, and the earliest records are of this kind. Thucydides, the Greek historian, tells us that, when Syracuse was attacked by his countrymen in 215–212 B.C., divers were sent down to break up the barriers that had been constructed below water to injure the Greek warships as they entered the harbour. More than 100 years before this, Alexander the Great had besieged the city of Tyre, and had been opposed by similar submarine defences.

At a later date, Livy, the Roman writer, refers to divers who descended into the sea to recover sunken treasure.

But all this had to be done without an artificial supply or air, and we can understand something of the magnitude of the task, and of the effort required to accomplish it, by a study of similar unaided efforts to-day. The pearl fisheries of Ceylon and the sponge fisheries of the Mediterranean are carried on in the same primitive fashion as in olden times. Bearing a heavy stone, to which a rope is attached, the diver jumps overboard from a boat. Down he goes for 120 or 150 feet to the bottom, collects rapidly his spoil, and gives the signal to be hauled up. The longest time that one has been known to remain under water is two minutes, and you can obtain a clearer notion of what this means by trying how long you can hold your own breath. You must, moreover, remember that the diver's body is all the time being squeezed by the water. This pressure is roughly 1 lb. on the square inch for every two feet of depth, so that at a depth of 100 feet the extra pressure to which the body is subjected is 50 lb. on the square inch. If we assume that a man has a body surface of 15 square feet, or 2,160 square inches, the ordinary atmospheric pressure is 32,400 lb., and the extra pressure due to the water 100 feet from the surface is 108,000 lb., or about 48 tons. So great is the strain, that after a number of deep-water dives even the natives often become insensible, and bleed from the nose, ears and mouth.

During the Middle Ages, when men were seeking to break away from old traditions, many attempts were made to provide a supply of air which a man could take down with him. No satisfactory diving-dress was produced until Augustus Siebe invented one in 1819. This was known as an " open " dress, and consisted of a



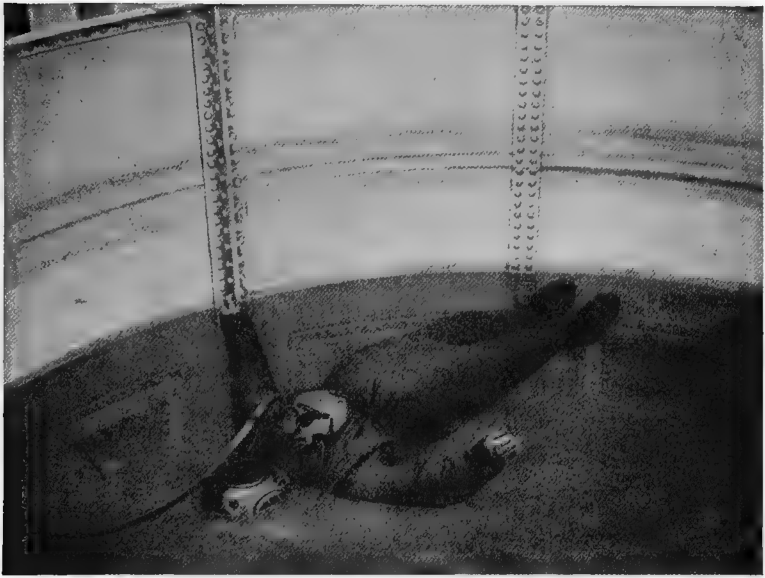
By permission of Messrs. Siebe, Gorman & Co., Ltd.

DIVING DRESS.

metal helmet and shoulder plate attached to a water-tight jacket, under which, fitting closely to the body, were worn trousers, or rather a combination suit reaching to the armpits. Fresh air was delivered to the helmet through a flexible tube connected with a pump at the surface, and escaped below the edge of the water-tight jacket. This dress was used for a number of important operations, but suffered from the disadvantage that, if the diver did not keep upright the water filled the jacket and he was in danger of being drowned. About eighteen years later, therefore, Siebe introduced the "closed" dress, upon which all diving dresses of the present day are based.

The modern equipment of a diver consists of a tinned copper helmet with three glass windows, which screws on to a corselet, or breastplate, of the same material. The corselet rests over the shoulders, and is attached firmly to a suit composed of sheet rubber between two layers of stout canvas. The cuffs are of vulcanized rubber, and are clipped to the wrists by rubber rings. In order to prevent the accumulation of air in the legs of the dress and the possibility of the man's being blown to the surface head-downwards, the legs are usually laced tightly up the back. The air sent down by the pump then collects in the helmet and upper part of the dress, and the excess escapes through a valve on the right-hand side of the helmet. This valve can be adjusted by the diver himself.

In order to enable him to sink, he carries a 40 lb. leaden weight on his chest, and a similar weight on his back, and there is 15 lb. of lead on each boot. Altogether the weight of the outfit is about 175 lb. He descends by means of a "shot-rope"—a rope with a 50 lb. weight at the end—which has been previously lowered, and on reaching the bottom he takes with him a "distance line," one end of which is attached to the weight, so that he can always find his way back to the shot-rope. Ascent and descent are made easier by adjusting the outlet valve, which controls the amount of air in the dress and thus enables the buoyancy to be varied.



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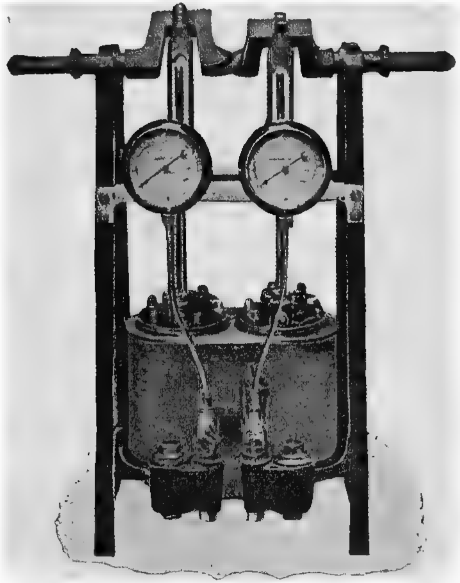
SHOWING THE HELPLESS POSITION OF A DIVER WITH HIS DRESS INFLATED WITHOUT THE LACES IN THE LEGS BEING TIGHTENED. HE FLOATS IN A HORIZONTAL POSITION INSTEAD OF UPRIGHT.

This point is worth a little more consideration, and is rendered clearer by simple arithmetic. If the diver weighs twelve stone, and his equipment is 175 lb., his total weight is 343 lb. The force tending to make him rise or sink in the water is the difference between his own and the weight of the water he displaces. Now, a fully-equipped diver with his dress deflated, or empty of air, displaces about 336 lb. of water, so that the force tending to sink him is 7 lb. But when the dress is fully inflated he displaces about 694 lb. of water, so the force tending to send him up is no less than 351 lb. By altering the outlet valve in such a way as to retain the air until the dress was fully inflated, he would, therefore, rise to the surface and float with rather more than half his body out of the water.

In addition to the shot-rope, distance line, and air tube, the diver has a rope attached to the breast, which is used for signalling; the air pipe is also used for this purpose. The breast rope sometimes has telephone wires embedded in it, leading from an instrument in the helmet to another one fixed over the ears of an assistant in the boat above. The diver of to-day is also equipped with an electric lamp, which enables him to see a short distance ahead, but the pioneer of 70 years ago had to work often in inky blackness and feel his way along the bottom.

The greatest depth in which diving operations can be undertaken has been decided by experiments made by Lieutenant Damant, R.N., and Mr. A. Y. Catto, Gunner, R.N., who found that work was quite possible down to 35 fathoms (= 210 feet) below the surface. But this can be done only when proper precautions are taken; for it must be remembered that, in order to keep up the air supply, the pressure of the air inside the helmet must always be a little greater than that of the water outside, and the diver is thus living in an atmosphere of compressed air. The additional pressure at a depth of 210 feet is about 100 lb. on the square inch.

If a man who has been exposed to great pressure returns to ordinary conditions too suddenly, he suffers very seriously. Bleeding may take place from the nose, ears and mouth; the lower part of the body may become paralysed; there are severe pains in the joints; and even death may ensue. For a long time the cause of these sufferings, which afflicted all men who worked in compressed air, baffled the doctors, but it has been discovered at last.



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DIVING AIR PUMP WORKED BY HAND.

The illustration shows a two-cylinder double-acting pump which can be used for two divers working simultaneously in moderate depths or for one diver in deeper water.

Air, as you know, consists mainly of two gases—oxygen and nitrogen. The oxygen is necessary for life. In the lungs it passes through fine membranes into the blood, combining with a substance called hæmoglobin, and being carried by it all over the body.

Under ordinary conditions nitrogen is not taken up by the blood to any appreciable extent, but, like all other gases, it becomes more soluble as the pressure increases. (For example, soda water is made by forcing carbon dioxide gas into water under high pressure. As soon as the bottle is opened, the gas in the form of bubbles escapes from its prison with great violence.) The blood dissolves nitrogen from compressed air, and yields it up when the pressure is reduced. The bubbles so formed interfere with the circulation of the blood and give rise to the sufferings that have been described.

It has been found that all the trouble is avoided if decompression occurs gradually, and a diver who has been down to any great depth for any length of time is not allowed to come to the surface immediately. He comes half-way up, and then rests awhile. Very elaborate tables have been drawn up by the British Admiralty, showing how long a man should remain down at each foot or so of depth, and how long he should take in coming to the surface. If a diver is blown up he is at once sent down again; but, if he is unconscious, artificial respiration is tried first. Sometimes a decompression chamber is used. This is a strong metal vessel in which the man is placed, and into which air can be pumped, and then the pressure reduced gradually. In this way diving operations are carried on with far less discomfort or loss of life than formerly. It has taken man many centuries to master compressed air to the extent of being able to live and work in it.

You may perhaps be under the impression that diving is an undertaking that occurs rarely, but in this you would be wrong. All over the world, at all times, there is work to be done under water which can only be done by means of compressed air. Now that we know what a diving-dress is like, we can take, in imagination, a journey under water and see what kind of work a diver has to do. Before doing so, let us see how divers are trained in the British Navy.

CHAPTER V.

Diving in the Navy.

EVERY warship in the British Navy has at least one diving dress, and one trained man who is capable of carrying out work under water. At Portsmouth Dockyard there is a tank specially fitted for the purpose of teaching men how to wear the dress, and how to act in various circumstances. It is about fifteen feet deep and twenty-five feet in diameter. Round the top is a platform upon which stand the men in charge of the breast rope, air tube, and telephone, and round the sides are strong windows through which the operations can be watched.

Divers are sometimes required to clean ships' bottoms. During a long voyage the portion under water becomes encrusted with barnacles; floating weeds and other matter become entangled by their shells, and the speed of the vessel is reduced. Though the cleaning is better done in dry dock, the work has occasionally to be undertaken at a port where no dry dock is available. The men stand or sit upon a sort of scaffolding slung over the side, or lie upon a net stretched underneath the ship's bottom, and use wooden scrapers or scrubbing brushes. In this way a man can stay beneath the surface for from four to eight hours, and can clean from seven to twelve square yards an hour.

Sometimes the propeller becomes fouled by a rope or wire hawser, and if this is twisted round very much it is no easy task to get it clear. In a very bad case the wire has to be cut, and for this a special wire-cutting machine is used. There are also valves below the water-line that need cleaning from time to time, and this again means work for the diver.

The old wooden ships were sheathed with copper because this metal remains much cleaner than another surface. But it corrodes rather badly and needs frequent renewal, especially in patches. The almost universal use of steel for ships has nearly driven out copper sheathing, and divers are now rarely engaged on this work.

Naval divers have often to recover lost anchors and other things of value, especially stray torpedoes. But perhaps the most important part of their training is to enable them to escape from a submarine vessel which, owing to injury, is unable to rise.

The word "submarine" tells you at once that it is a vessel intended to go under water. Along each side are large tanks, with valves which can be opened so that the water flows into them. As they fill, the boat sinks beneath the surface. The only way of getting into or out of the vessel is through a tower, called the conning tower, which has a ladder inside, and is closed by a sort of lid or hatch.

The air within is kept pure by absorption of the carbon dioxide by soda and the supply of fresh oxygen from time to time from steel bottles of the compressed gas. The smallness of the space in which the men are confined renders this very necessary.

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THE DESCENT INTO THE SEA.

If the hull of such a vessel is pierced by a shot, or torn by a sunken rock when the submarine is beneath the surface and the conning tower is closed, escape is very difficult. The water enters, and the vessel sinks like a stone. If this occurs in deep water nothing can be done, and the crew of from ten to thirty men are caught like rats in a trap. Two precautions, however, are taken to give them a chance of life if the water is not too deep.

The first of these is called an air-lock. From the upper portion of the interior there are vertical partitions, reaching say half-way down, behind which air must be trapped, however and wherever the vessel is "holed." Provided the air is pure, a man can live for a time; but there is some danger that it may not be pure, and the air-lock is relied on only as a means of giving the men a chance to put on a special form of diving dress in which the attempt to escape can be made.

This consists of a helmet attached to a short waterproof jacket, which slips on over the head and has tightly-fitting rubber wrist-bands. In the front of the jacket, on the inside, is a small case containing a substance which, when acted on by the moisture in the breath, yields oxygen gas, and a solid alkali which absorbs the carbon dioxide produced by breathing. The dress can be put on in thirty seconds, and the man can then work his way along to the conning tower and float up to the surface. He then inflates a flexible air-chamber which is part of the dress, and this acts as a life-belt.

Unfortunately, several submarines that have gone to the bottom during the last few years have done so in circumstances in which neither the air-lock nor the diving-dress have been of any avail. On one occasion, however, a submarine was accidentally sunk while in dock, and two men escaped by means of the air-lock alone. At the time no helmets were available.

Every man serving in a submarine has to go through a special course of training in the tank at Portsmouth. Structures representing an air-lock, the interior of a submarine, and a conning tower, are fixed up in the tank, and the men obtain practice in getting into and out of the air-lock, finding the entrance and climbing through the conning tower, and floating up to the surface.

CHAPTER VI.

The Romance of Diving.

In the last chapter we learned incidentally a little of the kind of work that a diver has to undertake. Whenever something has occurred under water about which further information is desired, a diver is sent down to investigate. Naturally the need arises most frequently in connection with shipping. If a vessel has run upon the rocks, a diver goes down to make an examination, and to ascertain whether a temporary patch will enable the water to be pumped out and the ship raised. If this proves to be impossible, then an attempt is made to get out the most valuable part of the cargo. In shallow water practically the whole cargo can be recovered, provided it is not too heavy or bulky. Thus, £300,000 in bullion[1] was salved from the *Malabar*, and cargo and silver specie to the value of £120,000 was obtained from the wreck of the *Queen Elizabeth*. From another vessel, *The Darling Downs*, laden with 725 bales of wool,

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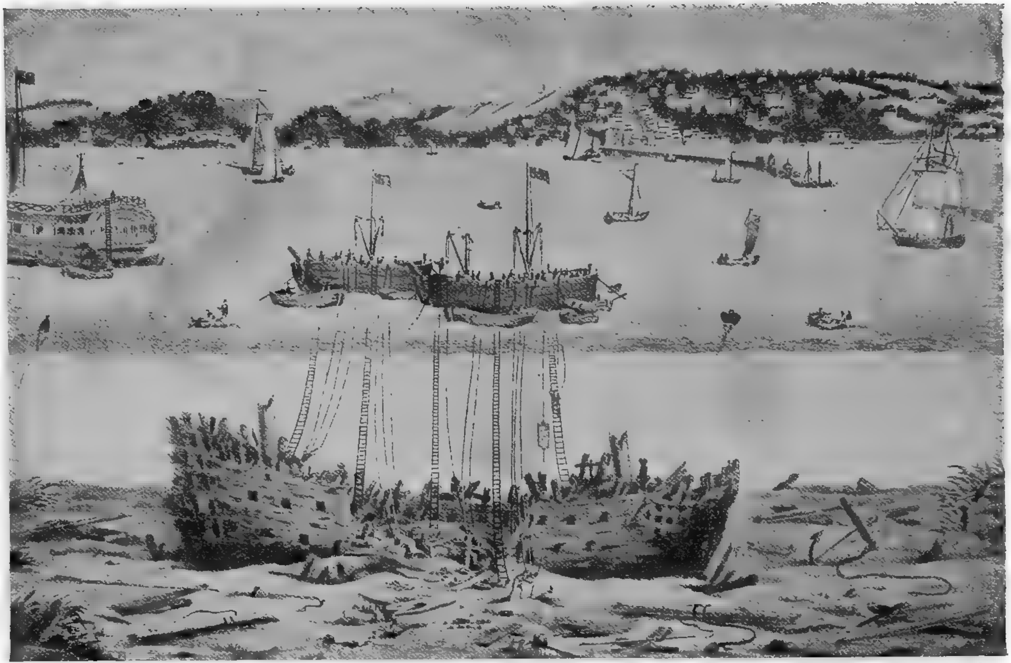
[1] *Bullion* means uncoined gold or silver; *specie*, coin. The recovery of cargo or the raising of a vessel is called *salvage*.

720 bales were recovered, which, together with some other cargo, represented a sum of £100,000.

One of the most exciting salvage operations ever performed was that by which £40,000 out of £50,000 in specie, carried by the *Hamilla Mitchell,* was won from the waters. The ship struck on the Leuconna Rock near Shanghai, and sank in deep water. After Lloyd's agent had reported the depth too great and the position too dangerous for any attempt to be made to salve the cargo, Captain Lodge undertook the task with diving gear supplied by Messrs. Siebe, Gorman & Co., to whom the writer is indebted for the information on "Diving" in this volume. The divers selected were R. Ridyard and W. Penk, of Liverpool.

After they had arrived at Shanghai the wreck had to be located, and, owing to the nearness of the cliffs, the search had to be carried on from a boat. They found that the ship had sunk upon a ledge and broken her back, the after-part, containing the treasure, rolling back into deep water. There, at a depth of about 26 fathoms, the divers worked their way into the treasure-room, where the worms had so eaten away some of the boxes that the money was lying in heaps across the floor. After having made four successful trips, in which £40,000 was raised, the men were resting; Ridyard being thirsty, Penk went up the hill to fetch water from a spring. Looking round, he saw to his astonishment a number of white sails coming from the mainland. These were soon identified by Captain Lodge as belonging to several hundred Chinese junks, which were in all probability carrying pirates. Sail was hoisted, and as the breeze was light every man lent a hand to the oars. For a little time they made little progress, but the wind at last freshened and they reached Shanghai in safety. They were not to be



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DIVERS AT WORK ON THE WRECK OF H.M.S. "ROYAL GEORGE," SUNK AT SPITHEAD IN 1782.

done out of the other £10,000, either; they returned and secured that on a later occasion.

An achievement attended by special difficulty, if not with unusual danger, was the recovery of £10,000 in silver bars from the wreck of the *Skyro*, which sank in 1891 while on a voyage from Cartagena to London. Off Cape Finisterre the weather became foggy, and the vessel struck on the Mexiddo Reef, passed over it, and went down in 20 minutes in deep water on the other side. The position was about 2 miles from the shore, and the depth over 28½ fathoms. An attempt to secure the silver in the same year failed, and another one four years later was also unsuccessful. In 1906 more powerful diving apparatus was obtained, and a diver named Angel Erostarbe was engaged for the work. The difficulties were many and great. The neighbourhood is exposed to violent storms, and there are also strong currents to contend with. The deck had collapsed to within 18 inches of the cabin floor. Charge after charge of dynamite was used to blow away the deck and make an entry into the strong room. When the winter came on, work had to be stopped until the following spring; but the silver was obtained, though it was necessary to blow the greater part of the vessel to pieces, until at last the only portions standing higher than a man were the engines and main boilers.

One of the most famous, as well as one of the earliest, achievements of modern diving was the salvage of the guns and equipment of the *Royal George*. This great battleship—one of the old "wooden walls of England"—carrying 104 guns, went down off Spithead in 1782. For more than 50 years she lay at the bottom of the sea, until the improvements in diving apparatus rendered it possible to reach her. In the year that Queen Victoria ascended the throne, an attempt was made to save some of the valuable metal in the ship, and for six succeeding summers men worked, raising the big guns one by one and sending up to the surface everything of value they could find.

The richest haul in gold that has ever been made was from the Spanish ship *Alphonso the Third,* which sank off Point Gando, Grand Canary, in 160 feet of water. The divers had to blast away the decks to reach the strong room in which the gold was stored. But they were successful, and Lambert, the famous diver whose exploit in connection with the Severn Tunnel has been referred to in *The Mastery of Earth,* recovered £70,000, while another diver brought up £20,000. Lambert's salary for this difficult and dangerous task was £40 a month with 5 per cent commission on all the gold recovered, the other diver receiving £30 a month and the same percentage.

And now, having shown how treasure is obtained from a wreck, let us see how a sunken ship itself is raised to the surface.

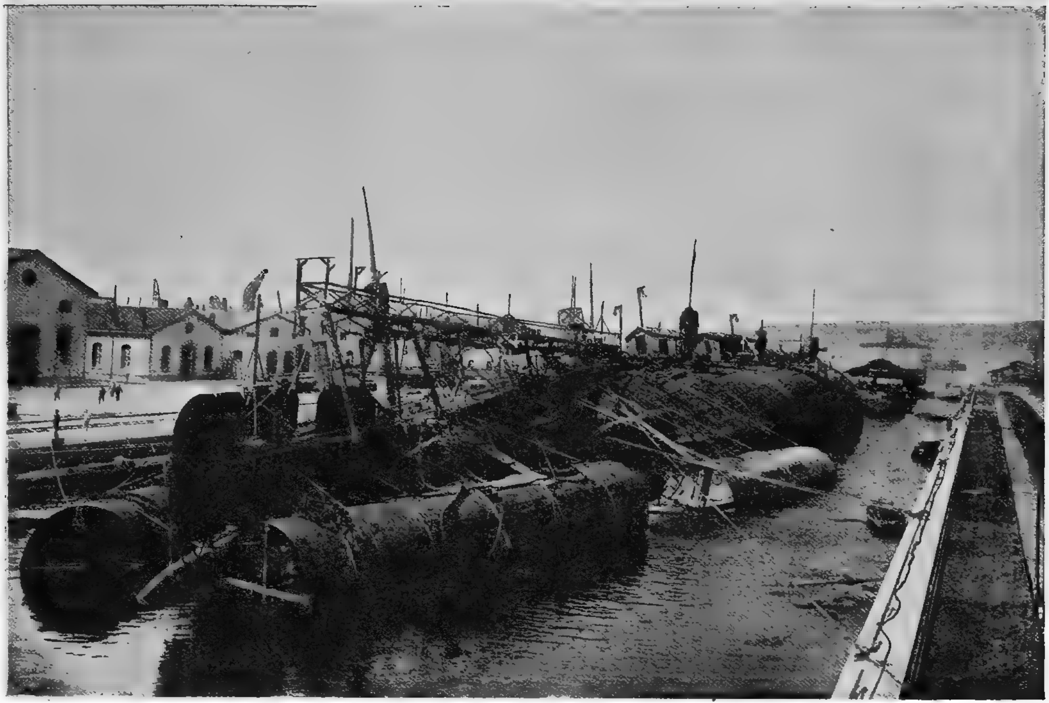
CHAPTER VII.

Raising the Wreck.

Do you know that on an average the value of ships and cargo lost at sea every year amounts to £9,000,000 ? Do you wonder, therefore, that there should be big companies which make it their sole business to recover cargo, and raise ships which are not too badly damaged and not in too deep water to render salvage impossible or unprofitable. These salvage associations keep ships specially built for the purpose, fitted with huge water and air pumps, powerful cranes, and a staff of skilled divers; and they are ready to obey a call from any part of the world. As ships are always insured, it is not the owner, but the underwriter who has guaranteed the owner against loss, who employs them; sometimes, too, the removal or destruction of the wreck is necessary, because it may be a danger to navigation.

The first step is to send down divers to ascertain the position of the vessel and the nature and extent of the damage. After that, the method adopted depends on their report, on the size of the vessel, and on the depth of the water. At every point there is need for knowledge, skill, and judgment, as well as courage; for stormy weather and strong currents may add to the difficulties of the task. The ship and her cargo may weigh no more than a few hundred tons, or they may reach a total of many thousand tons. The ship may have many feet of plating torn off. She may be lying on her side, or she may have actually "turned turtle" in her descent. She may have struck or settled on a ridge and broken her back, one half falling into deep water. Not only the preliminary examination, but the procedure for raising may have to be carried out 100 feet or more below the surface.

If a vessel is in shallow water it is sometimes possible to put a patch over the hole and then to build up round the hatch a water-tight structure like a big open box, called a coffer-dam. The water is then pumped out by means of powerful centrifugal pumps capable of lifting 150,000 gallons of water per hour. As the ship is lightened she rises to the surface. Should the water be too deep for a coffer-dam, the hatches are battened down, and the water is pumped out by means of one or more pipes passed through them.



THE CAPSIZED "LEONARDO DA VINCI" BEING FLOATED INTO DOCK BY MEANS OF CYLINDERS FILLED WITH COMPRESSED AIR.

Another method consists in mooring a couple of old hulks over the spot, and attaching to them the ends of wire hawsers which pass completely under the vessel. These hawsers are tightened at low tide, and as high tide is approached the wreck is lifted off the bottom. The hulks and their burden are then towed into shallow water, and the process of tightening the hawsers repeated when the tide ebbs again. When the rise and fall of the tide are too small to permit this method to be followed, the hulks are sunk as deeply as possible by pumping water into them, the hawsers are tightened, and then the water is pumped out again. The hulks may be aided or even replaced by pontoons—large wooden or steel rafts, made up in box form so that water may be pumped into or out of them.

The most interesting method, from the point of view of this book, is one in which compressed air is used. The hatches are battened down, and all other openings closed except one or more near the bottom, where the damage has been done. Air is then pumped into the vessel, and the water is expelled through the opening or openings left for it. Slowly the vessel rises, floating on a cushion of air, and may then be towed for many miles to the nearest dock.

An attempt to describe how even the more important ships have been raised by one or other of these methods would fill a volume larger than this; still, an example or two of each may be touched on lightly. The *Utopia*, sunk off Gibraltar in 50 feet of water, and the *Argus*, sunk off Birkenhead, were both raised by building coffer-dams and pumping the water out. In the first case, the coffer-dam was built round the gunwales, and had the effect of making a very deep vessel of the same length and beam. In the second the coffer-dam was built on deck; a similar plan was adopted in the case of the *Kottingham,* which was sunk in the fairway of the Tyne.

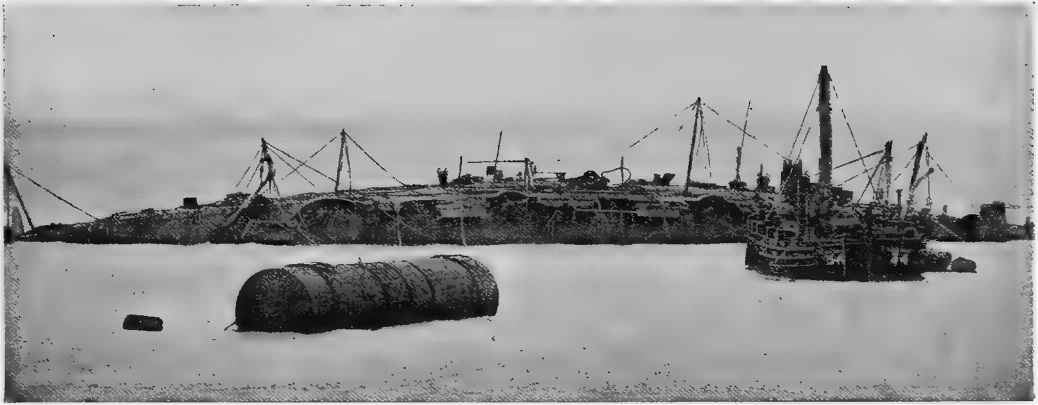
One of the earliest cases of the raising of an iron ship was the salving of the *Wolf,* a paddle-steamer 243 feet long, 27 feet beam, and 13 feet 8 inch draught, which was sunk by a collision in Belfast Lough about 10 miles from the shore. The depth of the water was about 45 feet, and the examination by the divers showed that the vessel was embedded in clay. As the difference in height between high and low tide is only about 9 feet it was decided to use pontoons from and into which water could be pumped. Messrs. Harland & Wolff, the famous shipbuilders, who had previously raised the *Earl of Dublin,* had available six pontoons capable of lifting 500 tons, and they constructed two larger ones each capable of exerting a lift of 216 tons. The vessel was estimated to weigh 850 tons, so that a 932-ton lift was judged to be sufficient.

The pontoons were moored in position over the wreck and fastened together by heavy beams. In each of the ports of the vessel divers placed strong wooden bars to which the lifting chains could be attached. As there were twenty-five ports on each side, the load on each chain was about 17 tons. No less than 200 men were employed in fixing the pontoons, and about 100 were required to work the winches. At the first attempt the vessel was carried about six feet towards the shore, but two of the lifting-chains then gave way, and the pontoons were damaged. From time to time other mishaps occurred, but slowly the vessel moved until, on the thirty-fifth day, it entered Abercorn Basin. The ship had been lifted 45 feet and towed 10 miles at a cost of £6,000.

On the 25th of April, 1908, a severe blizzard visited the Solent—that narrow strip of water which divides the Isle of Wight from the mainland. Among minor damages to shipping, the cruiser *Gladiator*, an armoured ship 320 feet long, 57½ feet beam, with a displacement of 5,750 tons, collided with the American liner *St. Paul*, and had to be run ashore. Examination by divers showed that the cruiser had her shell plating stripped off for a distance of 50 feet, and that the interior was open to the sea from the gunwale down to within 3 inches of the bilge-keel. She lay on her side on the shelving beach, in danger of slipping into deep water, in a spot where the tide runs strongly.

You would have thought that with such injuries the vessel was hardly worth salving, but a warship is a tremendously expensive thing to build, and this one was well worth a quarter of a million of money. The work was undertaken by the Liverpool Salvage Association, a body famous for its achievements in many parts of the world. The first thing to do was to remove the valuable fittings, which added to the weight. The guns, with their shields, weighing 15 tons apiece, were hoisted up. Then the funnels, ventilators, boats, davits, and other fittings were brought up. Where a fastening could not be loosened, tools worked by compressed air were used to cut the object away bodily.

The next step was to right the ship and draw her farther up the bank. She lay with a list of 93° to starboard, having fallen over on her damaged side in sinking. Two pontoons in the shape of cylinders, each 50 feet long, and 10 feet in diameter, and capable of lifting about 100 tons, were attached to the vessel to lighten her, and she was then pulled over by steam capstans set up on shore. Powerful pumps were used at the same time



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RAISING THE WRECK OF H.M.S. "GLADIATOR."

to lighten her. When the angle had altered by 10°, and the ship had been moved about 6 feet, the forward bridge caught in the sea-bed, and operations had to be stopped while it was removed.

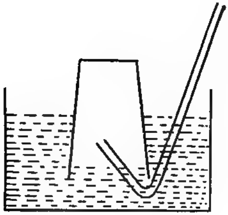
By this time five more pontoons were ready—one 75 feet by 12 feet diameter, two 50 feet by 12 feet, and two 40 feet by 12 feet. These were placed so that five exerted a pull on the damaged side and two on the other. They were sunk by admitting water through a valve, and raised by forcing in air at a pressure of 20 lb. per square inch. Tugs as well as capstans were brought into use, and 280 tons of pig-iron were placed on the port bilge keel to aid in righting the ship. When all these forces were ready, the pumps were set to work and flung out 6,000 tons of water per hour from those parts of the ship which were not open to the sea. Slowly the 5,000 tons of metal rose until the list to starboard was only 7°, but beyond this no headway could be made. The starboard side of the deck was still under water, so a coffer-dam was built, the pumps were again set to work, and the steamer was then towed into Portsmouth Dockyard for repairs. It was one of the most difficult examples of salvage ever undertaken.

CHAPTER VIII.

The Diving Bell.

If a glass tumbler is lowered into water mouth downwards, the water will rise inside higher and higher the more deeply the tumbler is immersed; but if there is some means of forcing air into it, as shown in the sketch, the water is driven down and may even fall to the level of the rim. Now, if this tumbler is replaced by a large metal box, in which several men can work at once, and a tube is connected to the top through which air can be pumped into the box, you have a proper Diving-Bell.

An apparatus of this kind is perhaps the oldest device for enabling men to live and work below the surface of water. It is supposed to have been invented by Roger Bacon, the clever old monk who is credited with the invention of gunpowder, about A.D. 1250; but he left no record of his discovery. In the literature of the Middle Ages there are several references to a vessel in which men could go under water; but the first really practical bell was due to Dr. Edmund Halley, Secretary of the Royal Society of London, and was made in 1717.



FORCING AIR INTO A TUMBLER.

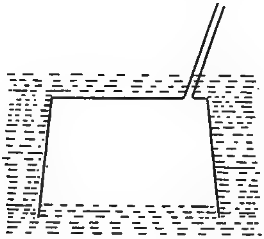


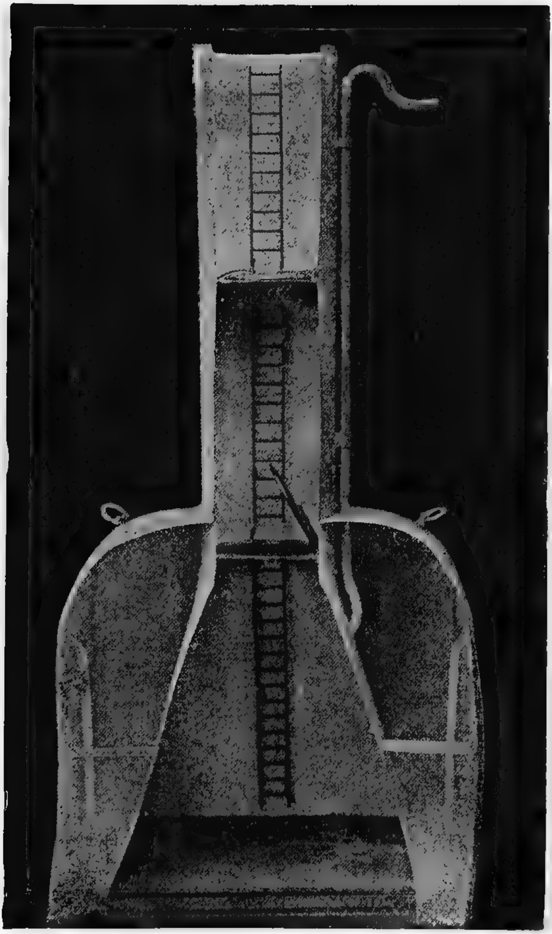
DIAGRAM OF A DIVING BELL.

His bell was constructed of wood 3 feet in diameter at the top, 5 feet in diameter at the bottom, and 8 feet in height. The outside was covered with lead, and weights were hung to the lower edge. A strong glass window was placed in the roof, and there was also a tap through which bad air could be let out. The most ingenious arrangement was that for supplying fresh air from time to time. An open barrel, fitted with a weighted flexible tube at the closed end, was lowered mouth downwards into the water at the side of the bell. The weight of the tube caused it to hang with its open end below the level of the mouth of the barrel, so that the air within was trapped. As the barrel descended below the level of the lower edge of the bell, where the pressure was greater than in the bell itself, one of the men inside the bell caught hold of the tube and turned the open end upwards. The water then rose in the barrel and drove air into the bell. By keeping two barrels at work, Halley and four others remained at a depth of 9 or 10 fathoms for an hour and a half without discomfort.

There is no record that Halley's Bell was used for any useful purpose, and, indeed, there was in those days very little need for submarine engineering. But when, in the latter half of the eighteenth century, Great Britain began to lay the foundations of her world-wide trade, there was great activity in building bridges across the rivers, and harbours and lighthouses round the coast. One of the most famous of the engineers engaged in this work was John Smeaton. In 1771 he was engaged in repairing the foundations of the piers of Hexham Bridge, and had to devise some means of enabling men to work under water. As the depth was small, he used a sort of open box turned upside down, with a pump mounted on the top, thus, for the first time, finding a better method of supplying air than Halley's barrels.

Three years later he was engaged in the construction of Ramsgate Harbour, and employed a square chest of cast iron, 4½ feet high, 4½ feet long, and 3 feet wide, weighing 2½ tons. This was heavy enough to sink by itself, and there was room for two men to work in it at once. The special job was clearing and levelling the foundation, and of the 160 tons of material brought up 100 tons were raised by the help of this machine.

Diving bells of this kind are used to-day for clearing



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STEEL AIR LOCK DIVING BELL.

foundations for the piers of bridges and for harbour works, but they are rarely so small as that used by Smeaton. They are constructed of sheet iron, and are 6 or 8 feet long, or even more, not less than 6 feet high, and 5 or 6 feet wide. They were used in laying the stones of the Folkestone Harbour Extension and of the new Admiralty Pier at Dover. The immense blocks of concrete were first lowered into place as nearly as could be done from the surface, and then divers went down in their iron box and made the final adjustments.

Do you think the men are nervous as they stand on a narrow shelf and see the water lapping hungrily at their feet? Not a bit. They know that the pumps are working steadily overhead; and they have the great advantage nowadays of electric light instead of the dull, smoky oil-lamps that used to be employed, and of the telephone by which they can communicate with the men in the boat above them. Even in the old days the men were unconcerned at the danger. Sir Francis Fox, in his interesting book, *By River, Road, and Rail*, describes how, in the work of repairing the piers of Westminster Bridge, the engineers were dissatisfied with the slow progress. After some trouble they found out that it was the practice of the men, as soon as the bell had disappeared below the surface, to produce a pack of cards and indulge in submarine "Nap."

The same writer, referring to another kind of nap, states that there is no cooler and pleasanter experience on a hot summer's day than to lie down on the bed of the sea with the diving helmet pillowed on a rock, and there to go to sleep until disturbed by a rude pull on the rope from the wideawake men in the boat above.

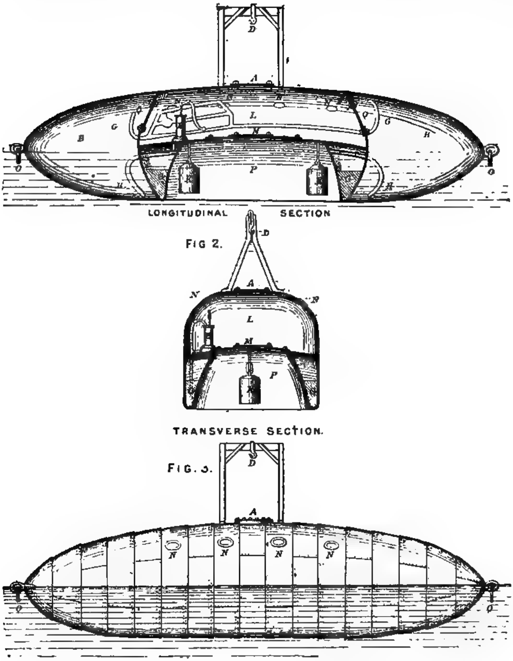
The man who goes down in a diving bell is, of course, subject to the same danger from breathing compressed air as the diver; and if the depth is more than about 5 fathoms the same precautions have to be taken. Dr. Leonard Hill, who has devoted a great deal of time to this problem, has invented a diving bell with two chambers, only one of which (the working chamber) is open at the bottom; the other is a decompression chamber into which the men can pass through a door, and in which the pressure can be varied at will. On ceasing work at the bottom the men go into this decompression chamber, and the bell is promptly hauled up to the surface. It is interesting to notice that in every branch of industry far greater precautions are now being taken to prevent sickness or loss of life. Even when the dangers were naked and threatening, there was no lack of men to face them. Now that the action of compressed air is understood, work in it is undertaken as lightly as work in the open air on the earth's surface, with the sun shining overhead and the wind blowing into one's face in invigorating gusts.

CHAPTER IX.

The Pneumatic Caisson.

YOU will know by this time that apparatus on machines worked by compressed air are described by the adjective *pneumatic*, and, therefore, you will not be alarmed at the title of this chapter. What the word "caisson" means will appear shortly. Meantime, we may say that it is a means of carrying on work below water on a larger scale than is possible with a diving-bell, and that it enables a man to work far more freely than if he is hampered by a diving dress.

The first practical contrivance for the purpose was a submarine boat invented by a Frenchman named Payerne, and constructed in 1844. The illustrations show that it was made of iron plates in the form of a boat with a hollow depression in the bottom—in fact not



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PAYERNE'S SUBMARINE BOAT.

unlike a boat turned upside down. It was 43 feet long and 10 feet deep, and weighed, with ballast, 62 tons. The end compartments could be filled with compressed air, the pumps for which were placed in the upper central compartment. The working chamber was below this, and fresh air was supplied from the end compartments every hour. One man was in charge of the pumps and eight men worked in the chamber below. They were able to remove 1½ cubic yards of hard rock in 6½ hours, besides ascending and descending twice in that time, partly to get rid of the stuff they had broken up. The machine was employed on the harbour of Cherbourg by the French Government.

It is, however, necessary not only to supply fresh air, but also to get rid of the carbon dioxide produced by the breathing of the men. When the work was carried on in running water this was easy; for carbon dioxide, being a heavy gas, sank to the bottom, and was dissolved and carried away by the water. If the machine was used in still water, a bellows was employed to pass the air in the working chamber through a solution of potash which absorbed the carbon dioxide.

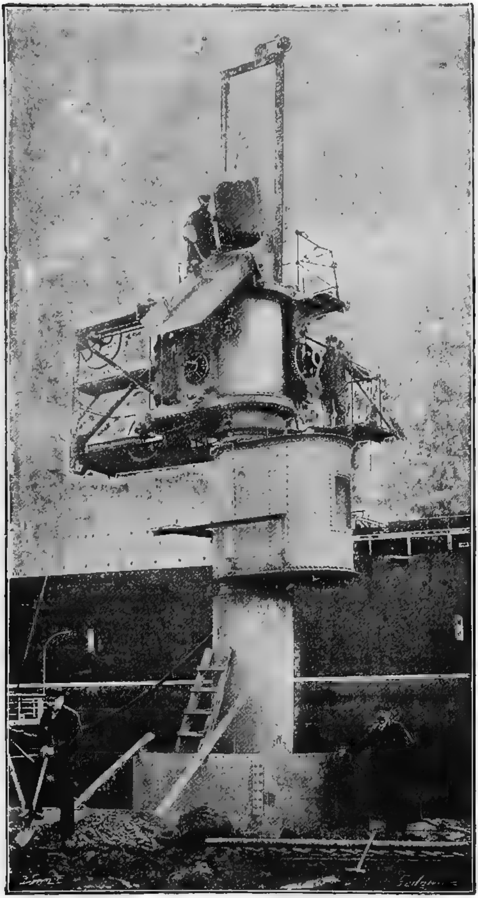
A submarine boat, however, is not effective enough for the great engineering works which have been carried out during the last sixty years. In that time enormous bridges have been built across wide stretches of water and swiftly-flowing streams, and the piers are sunk deeply into the rocks. Some account of these bridges has been given in *The Mastery of Earth*, but you will perhaps like to hear something more of the arrangements which enabled the water to be held at bay while the men laboured.

Now if you suppose an ordinary diving-bell to be fitted with a trap-door in the roof, and the sides extended upwards until they rise above the surface of the water, you will have a very good idea of a pneumatic caisson—with one detail left out. If the trap-door were to be opened while the caisson rested on the bottom, the water would immediately rise and fill the upper tube. To avoid this, the bell has a double top, forming another compartment called an air-lock, so that if only one door is opened at a time the men and material can be passed through with perfect safety.

The caissons used in building the piers of the Forth Bridge—one of the most wonderful pieces of bridge-building ever accomplished—were 70 feet in diameter, and one was about 90 feet high. They were constructed of steel, with double walls and strong girders, to prevent their being crushed in by the water. Only one partition was used, the men and materials passing between the lower or working chamber through wide tubes. The roof of the working chamber was weighted with concrete in order to sink the whole structure to the bottom.

The foundations for the caissons themselves had first to be levelled by divers. But, even then, the men in the working chamber could see the water lapping under the edges, and now and again coming in with a rush when a large bubble had escaped below.

The air-locks are situated at the upper ends of the tubes, and the illustration gives a good idea of a form of air-lock used by Sir William Arrol & Co., the well-known contractors. This is a single tube used for both men and material; there are two locks, the man-lock and the material-lock, placed one above the other. The lower lock, for the men, has two compartments. It is semicircular at the ends, with parallel sides, and there is room for three men in each compartment. The doors are of cast steel, with rubber joints, and light enters through bull's-eyes fitted in the walls. The joints are tested to a pressure of 50 lb. a square inch, and this will hold back the water at a depth of 100 feet. The pressure in each compartment can be regulated by means of taps. The fact that the compartments are duplicated enables one to be used as a decompression chamber,



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AIR-LOCK APPARATUS USED IN SINKING CYLINDERS WHEN BUILDING BRIDGES.

and thus a great deal of unnecessary suffering is avoided. The men who worked on the Forth Bridge gladly spent their Sundays in the caissons to ease their aching and swollen joints.

The material-lock has horizontal doors which slide open or shut, and the stones are brought up in buckets 2 feet 9 inches deep, 2 feet in diameter, and about 8 cubic feet in capacity. When working at a depth of 50 feet, the men can pass twenty buckets an hour through the lock.

Even work of this kind is not without its humorous incidents. Sir Francis Fox relates the story of a man who took a flask of brandy down with him, and, having drunk the contents, forced the cork in tightly. On leaving from the air-lock, the flask, to his great astonishment, burst in his pocket with a loud report. It was filled with air at a pressure of 30 lb. a square inch or more, and on coming into a region of lower pressure it exploded. If this is the effect upon glass you can only marvel at the resistance offered by the tissues of the human body. But, of course, a man does not put a cork into his mouth.

CHAPTER X.

Navigating the Ocean of Air.

THE navigator who is nearing an unknown coast " heaves the lead " to find the depth of water and thus avoid running aground. To a crab scrambling about on the bottom the depth is not of much consequence ; man, walking about on the earth's surface, was not, at one time, much concerned about the height of the atmosphere above him. But, having learned to run on land, to swim in, and propel and steer a ship upon, the water, he was not satisfied until he could be borne aloft on the wings of the wind like a bird. All other created things he had outstripped and beaten, yet his superior knowledge was insufficient to enable him to rise from the ground.

The idea of one day navigating the air is at least 2,000 years old. There is a Greek story of one Icarus, who made a pair of wings and, donning them, attempted to flap himself across the sea. But the wings were fastened on with wax, and, the wax melting in the sun, they fell off, and he was drowned. Throughout the Middle Ages there were various ingenious proposals for airships which came to nothing, and the first real, and to a certain extent successful, attempt was made in France towards the close of the eighteenth century.

At that time there lived in Annonay, in Auvergne, two brothers named Montgolfier. They were the sons of a successful paper manufacturer, and had their attention drawn to the possibility of enabling a light vessel to rise in the air by reading a French translation of Dr. Priestley's *Experiments Relating to the Different Kinds of Air.* It occurred to them that a light paper bag held with its mouth downwards might be filled with the hot air rising from a fire, and as this air would be very much lighter than the air that the bag displaced, the bag would rise. Some preliminary experiments soon established the truth of their supposition, and they proceeded to make experiments on a grander scale. A bag of 600 cubic feet capacity having broken the strings that held it down, and floated away to a great height, they made one measuring 35 feet in diameter and 23,000 cubic feet in capacity, using linen as well as paper in its construction. This rose to the height of about 1,000 feet, and came to earth a mile away.

In the year 1783, they began to give public exhibitions, and on June 5 a huge balloon was filled by holding it over a hole in the ground in which straw and wool were being burned. As the hot air gradually displaced the colder air inside, the enormous bag required eight men to hold it down; and when at last it was released it shot upwards until it was almost lost to view. After ascending about 6,000 feet it gradually descended and fell into a field a mile and a half away.

Let us consider for a moment the lifting power of hot air. All gases increase in volume at the same rate on being heated. 273 cubic feet of air at 0°C. (the temperature at which water freezes) will become 274 cubic feet at 1°C., 275 cubic feet at 2°C., 276 cubic feet at 3°C., and so on, provided that the pressure remains the same. At these three temperatures, therefore, the volumes are,

$$\frac{274}{273}, \frac{275}{273}, \text{ and } \frac{276}{273} \text{ of the original volume,}$$

and the weight of air in the original space of one cubic foot will be only

$$\frac{273}{274}, \frac{273}{275}, \text{ and } \frac{273}{276} \text{ of what it was at } 0°\text{C.}$$

Now, the weight of a cubic foot of air at 0°C. is approximately $1\frac{1}{4}$ oz. The total weight of the air displaced by a balloon of 20,000 cubic feet in capacity is therefore $20{,}000 \times 1\frac{1}{4}$ oz., i.e. 25,000 oz., at this temperature. If the temperature of the air inside the balloon was 91°C., its weight would be

$$\frac{273}{273+91} \text{ of 25,000 oz., and as } \frac{273}{273+91} = \frac{273}{364} = \frac{3}{4},$$

the difference in weight would be $\frac{1}{4}$ of 25,000 oz., i.e. nearly 400 lb.

This difference in weight is the force tending to lift the balloon. No sooner had it been discovered that such a frail thing as a linen and paper bag could be sent up with such power and yet descend safely, than men began to think of going up themselves. The first volunteer was Pilâtre des Rosiers, and his partner in the enterprise was the Marquis d'Arlands. By the end of November, 1783, the new balloon was ready. It was an immense bag, 28 feet in diameter and 74 feet high, with a capacity of more than 60,000 cubic feet. The hot air was supplied by a fire in a small brazier slung below the open end, and each man had a wet sponge to use in case the material caught fire.

A few trial trips were made by M. des Rosiers alone, with the balloon held captive by ropes; then he was joined by his companion, the ropes were let loose, and they set out on their adventurous voyage. When they found themselves falling, they stirred the fire; when the balloon threatened to carry them too high, they damped it. After a journey of several miles they landed safely, and showed for the first time how it was possible to make a journey in the air.

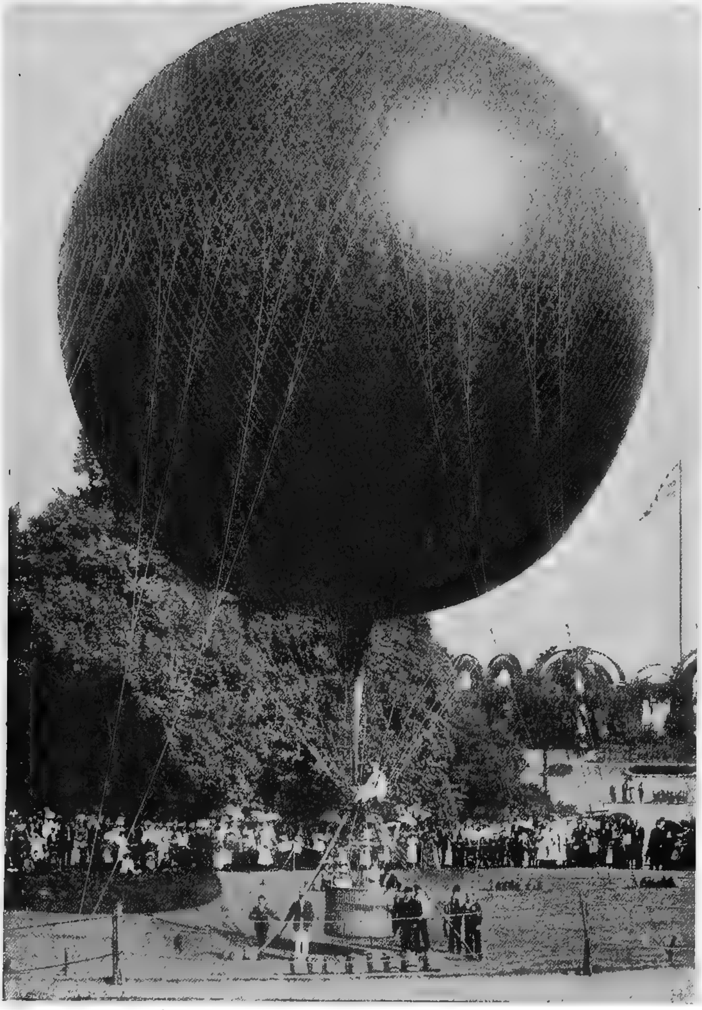
Early the next year a much larger balloon went up from Lyons. This was about 130 feet in height, and carried seven passengers. Up they went 3,000 feet above the ground, but, when the envelope suddenly split, and let out the hot air, they came down at a dangerous speed. They were fortunate in escaping without injury.

But now a far more powerful agent for giving buoyancy came into use. For a dozen years a number of men had been making discoveries in chemistry, and Dr. Joseph Black, of Edinburgh, had suggested the light gas hydrogen for the purpose of filling balloons. Hydrogen is prepared by acting on iron or zinc with sulphuric or hydrochloric acid, and is only about $\frac{1}{15}$th as heavy as air, bulk for bulk. The result is that a balloon filled with hydrogen has a lifting power of more than 1 oz. for every cubic foot of capacity, so that a balloon of 20,000 cubic feet would have a lifting power of more than 20,000 oz. or 1,250 lb.

A famous French chemist named Charles at once decided to make an experiment on a large scale. A balloon was constructed of 22,000 cubic feet capacity, and preparations were made to fill it with hydrogen gas. For this no less than 1,000 lb. of iron filings and 500 lb. of sulphuric acid were required, and four days were occupied in the process. On 27th August, 1784, the balloon was liberated in the presence of a vast crowd of people. Immediately it shot up to a height of 3,000 feet, remained in the air for a quarter of an hour, and came down in a field 15 miles away, where it was vigorously attacked and destroyed by peasants armed with pitchforks!

The value of a balloon in war was soon recognised. When Napoleon set out to reduce the nations of Europe to his imperial will, the ingenuity of man was directed towards improving the weapons of war, and captive balloons, rising to such a height that the disposition of the enemy could be observed, were used with great effect against the Austrians. After 1799, however, he gave them up, and they were not used much in warfare until 1840. In the meantime, coal gas, which had been introduced for public lighting by Murdock soon after 1800, came into use in place of the more expensive hydrogen. But it is nearly eight times as heavy as that gas, and so will not support so much weight per cubic foot.

The reader who examines a balloon will find that there are all sorts of details connected with its construction and management which he would hardly be likely to think of by himself. In the first place, the bag or envelope



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A SPHERICAL BALLOON OF 80,000 CU. FT. CAPACITY USED FOR CAPTIVE AND RIGHT-AWAY ASCENTS.

is composed of silk, treated with a varnish which renders it water-tight and prevents gas from escaping. The earlier ones were pear-shaped, but modern ones are always spherical, with a narrow neck pointing downwards. This neck is left open, for as one ascends the pressure of the atmosphere decreases very rapidly, and under the reduced pressure the gas inside expands. If the neck was closed the balloon might burst.

There is not so much danger, if this happens, as you might imagine. It has occurred on several occasions, and the bag, as it becomes empty, bulges up from below, forming a sort of umbrella or parachute which steadies the fall. About parachutes, however, we shall have something to say presently. Meantime let us return to the open neck.

As the balloon rises, some of the gas escapes through the neck; and as the balloon falls, air may enter to take its place. But all the time there is a slow exchange of air for gas, and this causes the balloon to lose buoyancy gradually. On that account, no balloon can remain in the air for many hours unless it has a large reserve of ballast. The mention of ballast brings us to the car.

The car is made of light material—often wicker-work—and is suspended by ropes attached to a strong net covering the whole envelope. In addition to the aeronaut and his companions, if any, and the necessary instruments and food, a number of bags of sand are carried. If the balloon descends too low some of this ballast is thrown out, thus reducing the weight the balloon has to support. In the course of a long journey the ballast becomes exhausted, and sooner or later the balloon comes to the ground.

It is just as necessary to be able to come down at will as to be able to ascend. This is effected by means of a valve in the envelope through which gas can be allowed to escape. This valve is worked by a cord leading down to the car. If it is used too frequently, of course, waste of gas occurs and the journey is shortened, so it is employed only in case of necessity.

You may, perhaps, wonder at first why this necessity arises. A little reflection will show you that there is a limit of altitude beyond which man cannot live. He needs oxygen, and obtains what he requires with every inward breath. But the lungs cannot hold more than a certain volume at a time, and in the rarefied air in the upper regions of the atmosphere the amount that can be inhaled is not enough to support life. Several aeronauts have lost their lives by suffocation, which simply means that they have been deprived of the necessary amount of oxygen.

Landing is perhaps the most dangerous part of ballooning, even when the ground is favourable. It is not easy to regulate the speed of descent, especially when the ballast is exhausted, and the least that can be expected is a violent bump. There is, moreover, the danger that if one passenger leaves before the others, the lightened balloon may set off on a great journey with a man so far worn out with fatigue that he is unable to manage the unruly craft. To a large extent, this danger is averted by a *ripping panel*, which consists of a slit in the fabric over which a patch is lightly stitched. A cord is so arranged that when it is pulled the patch is torn, and the gas escapes.

A balloon of the ordinary type cannot be steered. It moves with the wind, and there is no pressure to act upon a rudder. But if a long rope is suspended from the car with its end dragging along the ground or through the water, then the movement of the balloon is retarded and a sail set upon a long rod can be used to steer it to some extent. In the same way a drifting boat cannot be steered; she must move either more or less rapidly with the current.

CHAPTER XI.

Famous Balloon Voyages.

EXCEPT among a few adventurous spirits, and the members of the military balloon staffs, ballooning has never become a favourite pastime or means of locomotion. Probably most boys and girls have seen a balloon ascent at some flower-show or fête or gala, and from time to time the newspapers have recorded some remarkable aerial voyage, or the total disappearance of men who have trusted themselves to the uncharted air. But for the most part the records of wonderful journeys and thrilling escapes are buried in books read only by those who are especially interested. Let us dig out of obscurity some of these accounts, and endeavour to feel something of the enthusiasm for daring which these men have displayed.

First and foremost, let us recall the great achievement of Mr. J. W. L. Glaisher and Mr. H. Coxwell, who ascended to a height which, if it does not constitute the record, falls very little short of it. Coxwell was a professional aeronaut, and Glaisher a scientific man interested in the exploration of the ocean of air. On September 5, 1862, they ascended from Wolverhampton, and climbed steadily to the height of 29,000 feet. At that point the reduction of the amount of oxygen began to have its effect upon them. In his book, *Travels in the Air*, Mr. Glaisher says—

"Shortly afterwards, I laid my arm upon the table possessed of its full vigour, and on being desirous of using it, I found it powerless; it must have lost its power momentarily. I tried to move the other arm, and found it powerless also. I then tried to shake myself, and succeeded in shaking my body. I seemed to have no limbs. I then looked at the barometer; and, whilst doing so, my head fell on my left shoulder. I struggled and shook my body again, but could not move my arms. I got my head upright, but for an instant only, when it fell on my right shoulder, and then I fell backwards, my back resting against the side of the car, and my head on its edge; in this position my eyes were directed towards Mr. Coxwell in the ring. When I shook my body, I seemed to have full power over the muscles of the back, and considerable power over those of the neck, but none over either my arms or my legs; in fact I seemed to have none. As in the case of the arms, all muscular power was lost in an instant from my back and neck. I dimly saw Mr. Coxwell in the ring, and endeavoured to speak, but could not; when in an instant intense black darkness came, and the optic nerve finally lost power suddenly. I was still conscious, with as active a brain as at the present moment while writing this. I thought I had been seized with asphyxia, and that I should experience no more, as death would come unless we speedily descended. Other thoughts were actively entering my mind, when I suddenly became unconscious, as in going to sleep. I cannot tell anything of the sense of hearing; the perfect stillness and silence of the regions six miles from the earth is such that no sound reaches the ear."

After Mr. Glaisher had lost consciousness, Coxwell, who had also lost the use of his hands, pulled the valve cord with his teeth, and by this action enabled both to live to tell the tale. How high they ascended is uncertain, though Mr. Glaisher's estimate of 37,000 feet, or over seven miles, is now held to be too high. When they were next able to make accurate observations they were descending at the rate of 2,000 feet a minute, or 22½ miles per hour.

The sufferings of these two men at such an altitude were only what was to be expected from the reduced supply of oxygen, and are similar to those which have been endured by other daring men who have attempted to soar so high above the clouds. In 1901 two Germans ascended in the balloon *Preussen* to a height of 35,100 feet, and both were in a fainting condition for three-quarters of an hour. In all these high ascents it is now customary to take a supply of compressed oxygen in steel bottles, and to inhale a little as the altitude approaches 20,000 feet.

But, quite apart from any means of preventing faintness, how would you like to be suspended to a thin silken ball nearly seven miles above the surface of the earth. Out of sight, alone amid a deathly silence broken only by the sound of your own voice; and then a descent so rapid that the wind whistles through the cordage, changing its note as the car rocks slightly from side to side. Think what would happen if the silk bag split badly or the cordage gave way. A fall from the height of 37,000 feet would not take long; it would be completed in about 48 seconds; but the falling body would move with gradually increasing velocity, which, neglecting the friction of the air, would amount ultimately to over 1,500 feet a second, or about three-fourths of the speed of a bullet as it leaves the muzzle of a rifle: it would, at that rate strike the ground with a velocity exceeding 1,000 miles an hour!

The first long voyage from England to the Continent was made by Mr. Green in 1836, with Mr. Mason and Mr. Holland as passengers. The bag was 60 feet high and 50 feet in diameter, and held 85,000 cubic feet of gas. With such a volume, the balloon and its passengers might weigh as much as 4,000 lb. The ascent took place from the Vauxhall Gardens, and as the balloon passed over Canterbury and Dover letters were sent down by small parachutes. As night came on, while they were crossing the Channel, the balloon tended to fall because the moisture increased its weight relatively to the air, but this was compensated for by lowering a guide rope with floating ballast at the end. In the morning, or on the approach of land, this could be drawn up, or would come up naturally as the buoyancy of the air increased and the balloon rose.

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A BALLOON RACE STARTING FROM YORK GALA; EACH BALLOON IS SPHERICAL AND OF 35,000 CU. FT. CAPACITY.

The Channel was crossed rapidly, and the inky blackness was presently relieved by the twinkling lights of Liége.

In the still darkness they sailed on until the morning, when they descended safely at Weilburg in Nassau in Germany, having accomplished a journey of 500 miles in 18 hours.

The longest balloon voyage ever made was accomplished by Count de La Vaulx, in October, 1900, and covered 1,193 miles. It started from Vincennes in France, and ended at Korosticheff in Russia. For 35¾ hours the aeronaut was careering over hill and valley and open plain, often above the clouds and in the utter loneliness that falls when the earth is out of sight. In an attempt to beat this, A. E. Gaudron, J. L. Tanner, and C. C. Turner set off from the Crystal Palace on 12th October, 1901. They passed over Yarmouth, crossed the sea to the coast of Denmark, and landed on the shore of Lake Wener in Sweden. There they descended from an altitude of 8,000 feet into a pine forest, crashing through the branches and dragging small trees up by the roots. The total distance covered was 702 miles in 19 hours, and the 360 miles of sea represent the greatest distance over water ever crossed by a balloon.

On 18th November of the following year, A. E. Gaudron, Captain E. M. Maitland, and C. C. Turner made another long voyage. Starting again from the Crystal Palace, they crossed the sea to Belgium, and sailed merrily over North Germany. Late on the evening of the 19th they encountered a snowstorm and descended at Mateki Dereoni in Russia, having covered 1,117 miles in 31½ hours. In spite of the fact that they pulled the ripping panel open on touching ground, they were dragged along "over the frozen snow, through bushes and over a hill, for a distance of half a mile, coming to a stop on a frozen lake, with the basket turned completely over and all of us huddled up and shaken out of our wits inside."[1] This is the longest journey ever made by a balloon from Great Britain.

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[1] C. C. Turner, *The Romance of Modern Aeronautics.*

The thrilling experiences of the aerial voyagers who have dared the whirlwind and ridden upon the storm during the last hundred years would fill a bookshelf. Every now and then some one pays the penalty of his daring with his life, but the great majority live to tell their tale, and to exult in the mastery of the last of the four elements to yield to man's dominion.

CHAPTER XII.

"Limited Liability."

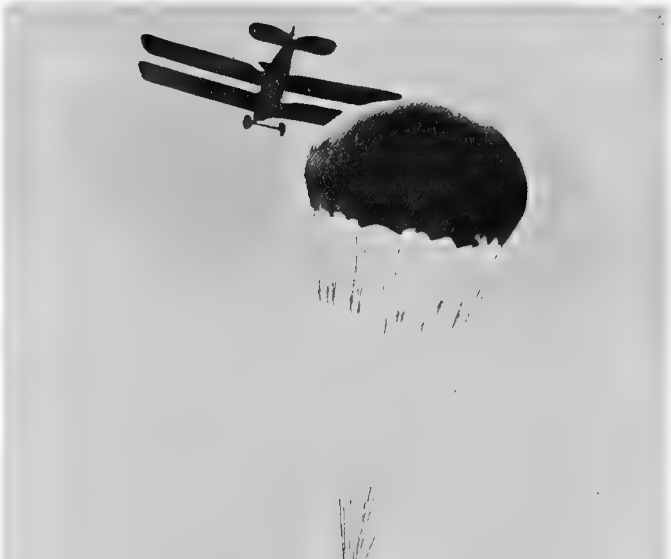
As you would expect, it is a disastrous thing to jump from a balloon, as it is usually attended by certain death. The difference between a fall of 200 feet and one of say 6,000 feet is really very small, though an Irishman might say that it was a matter of being "kilt" or "kilt entoirely." But there is a method of leaving a balloon —or aeroplane—in mid-air with a limited liability to injury, and that is by means of a parachute. A parachute is like a big umbrella that opens out as soon as it begins to fall, and offers such a strong resistance to the air that even with a man or woman hanging to it its motion downwards is very slow.

There is an old and true saying that "Necessity is the mother of invention": man does not, as a rule, trouble about new methods and new machines unless he feels very strongly the need for them. And this fact is very well illustrated by the inventing of the parachute. When Napoleon was beginning to extend his power over Europe in 1794, one of his soldiers, Jacques Garnerin by name, was taken prisoner by the Austrians and confined in the fortress of Buda. During the three years of his imprisonment, he thought of many plans of escape, one of them being to throw himself from the ramparts without being injured. If he could only attach himself to something having little weight but a large surface, he felt that he might launch himself into space with safety. But the trouble was to obtain a suitable surface, and the experiment had to wait until he was liberated and returned to France in 1797.

Let us look for a moment at the principle involved. Consider first a ship sailing before a five-knot breeze. The pressure of the wind on the sails drives the ship with its load through the water. Let the breeze fall, and the sails flap idly against the masts and spars. Suppose now a rope attached to the stern and the ship dragged backwards with a speed of five knots. The sails will now fill out as before, the force required being that which was exerted by the wind in the first instance.

When, therefore, a body moves through the air a considerable force which tends to prevent the motion is exerted on its surface. The tendency to form eddies and whirlpools makes the calculation of this force very difficult, but it will be clear that the resistance to motion will be greater as the area of surface is greater, and will increase as the speed of the moving body increases. Garnerin calculated that a surface of thirty-three square feet would offer such a large resistance that it would support his weight, and yet fall so slowly that no injury need be feared.

The attempt was therefore made. He attached his parachute to a balloon by a cord which could easily be cut, while he himself sat in a loop of rope attached to the parachute. One would have thought that the first attempt would be made from a small altitude, so as to



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A PARACHUTE OPENING OUT A FEW SECONDS AFTER BEING DROPPED FROM AN AEROPLANE.

reduce the risk of injury; but a great height is an advantage, because the fall is very rapid until the parachute has had time to open, and the full resistance of the air to become effective. So Garnerin did not cut the cord until he had soared 6,000 feet. Relieved of its weight the balloon shot upwards into the clouds, while the parachute, swaying from side to side, came down slowly to the ground.

This successful attempt led to many others. The principles were only partly understood, and experimenters took risks to prove the truth or falsity of their views. The chief defect was the dangerous swinging during descent, in which the parachute threatened to turn upside down or crumple up. Henry Cocking thought that this could be avoided by making the parachute with sides sloping upwards like those of an umbrella that has been blown inside out by the wind. In spite of advice, he made the attempt in June, 1837, and liberated himself, at a height of 5,000 feet. For a short distance the parachute fell steadily; then began to swing violently; finally coming to earth with a crash. The unfortunate inventor of this type of parachute proved its unsuitability at the cost of his life.

The cause of the oscillation, or swinging, is the tendency of the air to accumulate under the parachute. This escapes under the edge from time to time, now on this side and now on that, rendering the motion unsteady. Modern parachutes are about 39 feet in diameter when flat, about 30 feet when buoyed up by the air, and are capable of supporting a weight of 200 lb. There is a hole in the centre through which the entrapped air can escape, instead of under the edge; and the pressure is produced by the air flowing smoothly over the under-surface. Twenty feet below, the parachutist sits in a

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A MAN DESCENDING BY PARACHUTE FROM AN AIRSHIP.

small car. With such an apparatus the descent is extremely gentle, being sometimes as slow as only 120 feet a minute, i.e. 2 feet a second.

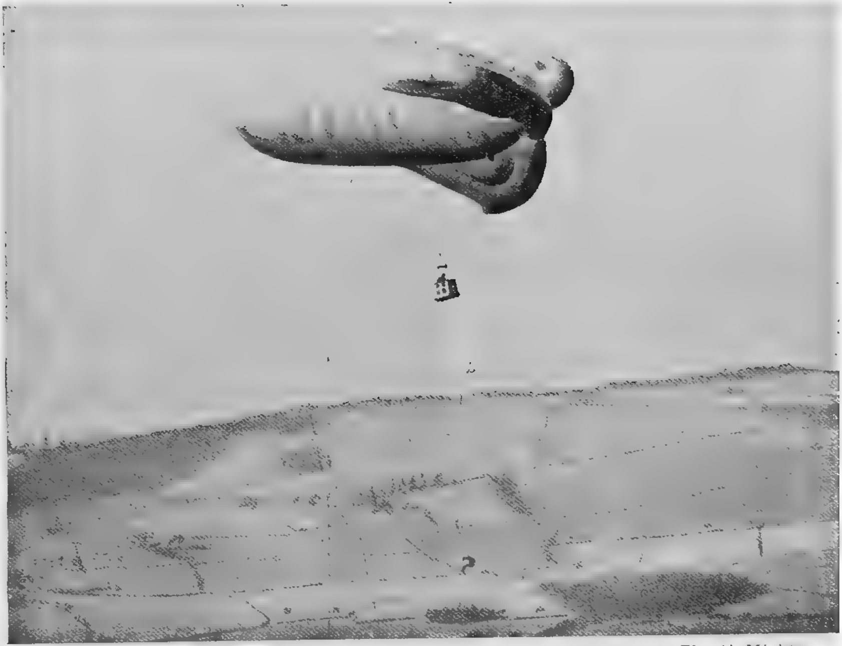
CHAPTER XIII.

The Balloon in War.

WE have already learned that the great military genius, Napoleon, used balloons in his earlier campaigns, and found them of great use in directing the fire of his artillery. But for some reason he gave up their use, and for forty years they were not employed in war to any extent. The next occasion on which their value in war was demonstrated was in the struggle between the Northern and Southern States of America in 1862. But they will always be remembered in connection with the Siege of Paris in 1870.

You have probably read in your history that in the middle of the last century Germany consisted of a number of independent states, and that soon after 1860 Prussia set herself to build up a great German nation in Central Europe. In 1866 she turned upon Austria, and seven weeks later totally crushed that power on the field of Sadowa. Four years after this, she went to war with France. In September, 1870, the French Emperor and 83,000 men were forced to surrender to the Prussians at Sedan, and in October the fortress of Metz capitulated. The genius of Moltke, the Prussian commander-in-chief, and the unpreparedness and bad management of the French army, led to one of the most rapid and decisive wars of the world.

When the army on the frontier was beaten and the Emperor was a prisoner, the Prussians laid siege to Paris,



By permission of *The Air Ministry.*

KITE BALLOON ON OBSERVATION DUTY.

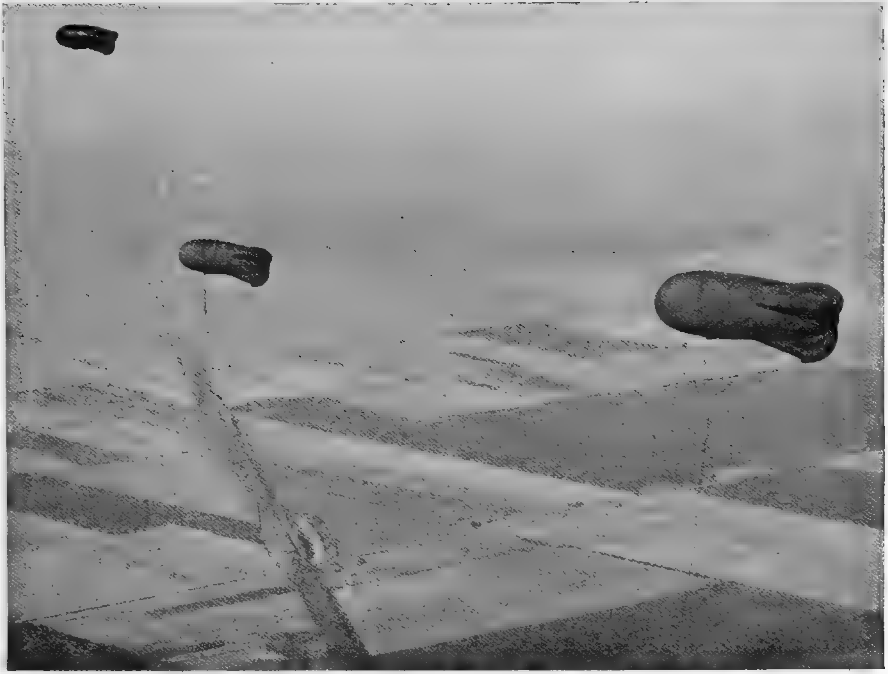
Note the parachute just released and in process of opening.

and for four weary months the city was surrounded by a ring of steel. Shut off from the world on every side, and with a dwindling stock of food, the only means of communication was through the air. From time to time carrier pigeons and balloons left the beleaguered city, the balloons floating high up among the clouds, over the heads of the Prussians, and generally well out of range of their rifles.

The pigeons could not, of course, carry a heavy burden, but a means was found of reducing this to an extraordinary small size. Thirty-two pages of print were photographed on a thin piece of paper 2 inches long and 1¼ inches wide, weighing less than 1 grain. This was rolled up and inserted in a quill, which was attached to the bird, and the message was afterwards read by projecting it enlarged on a screen by a lantern. The charge made by the men who organized the pigeon post was ½d. a word, so that the value of a full message was about £66.

The balloons were sent up from two stations, one in the north and one in the south of the city, and sixty-six of them floated away on their desperate journey over the Prussian lines. They conveyed sixty-six aeronauts, 102 passengers, between 400 and 500 carrier pigeons, six dogs, and nine tons of letters. Sixty-one of them escaped capture. You can imagine the tense excitement as each balloon rose from the ground, and the feeling of relief and hope as it soared into the clouds; and you can read in the books on the Franco-German War something of the misery and suffering of the people who told their tale in the nine tons of letters carried by the first aerial post the world had known.

But apart from this service, balloons were used by both sides in directing the fire of artillery, as they have been in every important war since then. The British



By permission of *The Air Ministry.*

THE BALLOONS USED TO SUPPORT AN APRON OF STEEL WIRE AS A PROTECTION AGAINST HOSTILE AIRCRAFT.

Army used them in the Egyptian campaign of 1882, in the Boer War of 1885, in the South African War of 1910, and in the recent Great War.

Improvements in photographic cameras have enabled some wonderful pictures to be obtained, showing in a marvellous way the curious appearance of familiar buildings when seen from above. From a point high up in the air the country below is spread out like a map, and the positions of regiments and fortifications are recorded with far greater precision than can be attained in a sketch. But they were necessarily captive balloons, and their height was limited, so that with the long range and precision of modern artillery and small arms the balloon has gradually become of smaller importance.

CHAPTER XIV.

Flying Kites.

WHO has not flown a kite and rejoiced to feel the pull on the string as the wind got a fair hold on it? Surely at some time or another every reader of this book has had the satisfaction of standing with his back to the wind and paying out string to the last inch. What a disappointment when this point is reached, and the kite can go no higher! Like a good many other toys, kites have been put to a useful purpose by grown-up men, and if the boys in past years had not adopted them as a pastime, it may well be doubted whether the aeroplanes of the present day would ever have been invented.

If you want to understand aeroplanes you cannot do better than try to understand kites, and as every one nowadays needs to take an intelligent interest in his surroundings, you will not object to a little hard thinking of this sort. Moreover, when once a difficult problem is understood, there is as much satisfaction as in winning a race.

First, then, notice that there is a pull on the string, and that this pull is one of the forces that keep the kite in the air. Secondly, since every body has weight, and weight is a force of attraction between the body and the earth, there is a force acting downwards. Thirdly, there is the force produced by the wind blowing upon the kite's surface. And these are all the forces concerned in maintaining the kite aloft.

Now the weight is constant, and can be found once and for all before the kite is sent up. The tension in the string can be measured by first ascertaining how much an inch of rubber cord is stretched by different weights, and then inserting the cord in the string and noting the increase in length. But the force of the wind you cannot measure. However, this does not matter, because any calculation that could be based on it would be of very little value. Let us concentrate our attention on the pull on the string.

If you haul in the string, what happens? The kite moves towards you, and rises. If you pay out string, the kite moves away from you, and falls. The pull on the string may therefore be regarded as consisting of two parts: one acting upwards against the weight, and the other acting horizontally against the wind. The first is called "lift," and the second, "drift." As the weight is the same all the time, every change in the force of the wind has to be met by taking in or paying out string—that is by increasing or decreasing the tension in it.

Suppose now the force of the wind increases. The string becomes tighter ; part of the tension in it is given up to preventing the kite from being blown away, and part, now greater than the weight, lifts the kite higher. If the strength of the wind decreases, the string becomes slacker, and that part of the force in it which has previously been equal to the weight now becomes less, and the kite falls.

All these effects are complicated by the fact that the kite can change its inclination to the wind, and the use of the tail is to give it such an angle that the greatest amount of lift is secured. If the tail is too light, the lower end of the kite rises, and the wind glides by instead of supporting it. If the kite is vertical, the *drift* is at its greatest value and the *lift* at its lowest. As the lower end rises, the drift decreases while the lift increases—though, when a certain angle is passed the lift begins to decrease again.

A very little experience will show that a large kite takes a good deal more holding than a small one. A wind of a certain velocity—20, 30, or 40 miles an hour—exerts a definite pressure on a square inch, and the larger the surface upon which it acts the greater is the amount of lift obtainable. On this account, " box kites," which were invented by an Australian named Lawrence Hargrave in 1884, are much more effective for their size than those of the ordinary form. In a wind of a definite strength, they will rise more freely ; and they will go up more easily in a lighter wind.

A large kite, especially one of the box form, will easily lift a man, and the British Army made many experiments with a view to using them instead of balloons for scouting. The late S. F. Cody, the famous aviator, was a great believer in their use and held an official position in the Royal Aircraft Factory in connection with them.

On one occasion he crossed the Channel from Calais to Dover in a small boat drawn through the water by a man-lifting kite. At high altitudes, the wind is much steadier than near the ground; everybody knows that the chief trouble in kite-flying is to get the thing to go up. When once it is up, it stays there as long as the wind holds and the string is not hauled in.

CHAPTER XV.

Gliding.

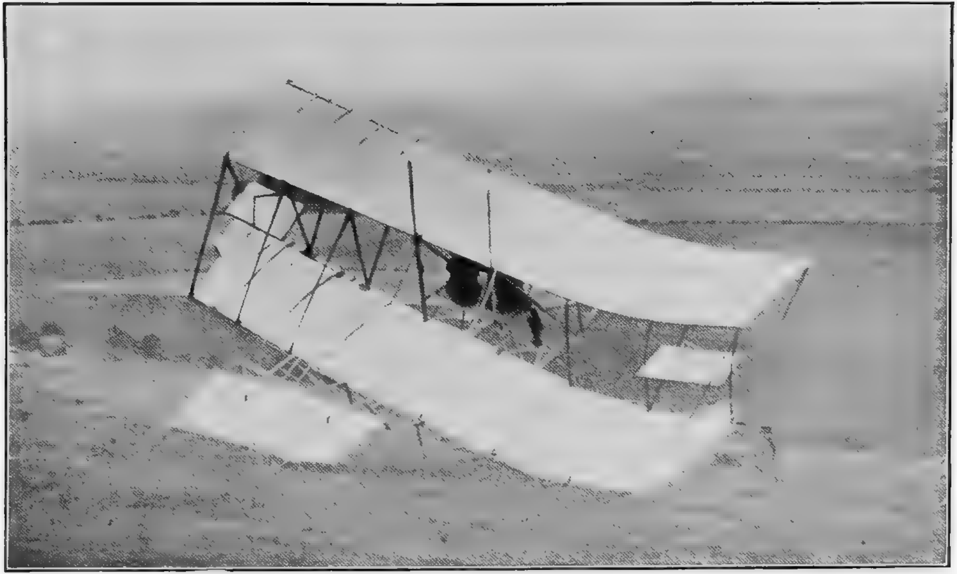
THE aeroplane came with a rush, and up to the very last moment many people refused to believe that aerial locomotion would ever become possible. Success was achieved only after a long struggle in which men risked their money and their lives—and lost them both in the attempt. To a few men success appeared certain sooner or later, and there was one who, a hundred years ago, stated exactly the conditions that were necessary. That man was Sir George Cayley. He showed that if a flat surface at a slight angle to the horizontal could be driven through still air, or against the wind, or in the same direction as the wind but faster, it would support a considerable weight. But the engines of his day were all too heavy for the experiment to be made.

During the nineteenth century a number of proposals for flying machines were made, but most of these were unworkable. The chief kind was one that is made to-day, one for which patents are still being taken out. It was a machine with screws like the propeller of a ship, working on vertical shafts and meant to lift the machine in the air, in much the same way as a ship is drawn backwards through the water. No workable machine of this kind has ever been made, though it is not necessarily impossible.

In 1870, a German named Otto Lilienthal began to make attempts at gliding through the air. He had studied very closely the flight of birds, especially over water, and he had a large pair of wings constructed which he could grasp in his hands, and hold after launching himself in the air from the top of a hill. The wings consisted of a light wooden framework, covered with canvas, having a curved surface of about 160 square feet in area. In the centre was a space for the aviator's body, and the apparatus was grasped firmly by the hands. Balance was controlled by swinging the legs. The whole apparatus weighed only 40 lb.

The first experiments were made by jumping off a spring board about four feet high. Practice brought confidence and skill, so that he soon began to increase the height. Sometimes he ran down a gentle slope in the teeth of the wind, rose in the air, and alighted softly 250 yards away. In order to get better practice, he had a mound 50 feet high built on the outskirts of Berlin, which enabled him to face the wind from whatever direction it was blowing. As time went on he grew more and more daring, often making long glides when the wind was blowing hard, and in 1896 he met his death through a bad fall: a sudden gust of wind caught the machine, lifted it up, and then dashed it to the ground. But his experiments had attracted a great deal of attention, and had shown that a surface, started at the right angle against the wind, was capable of supporting a man's weight with ease, and that, with practice, sufficient skill could be attained to vary the height and direction of flight.

Shortly before Lilienthal's death, Percy S. Pilcher, a



A GLIDER COMMENCING A FLIGHT DOWN A HILL.

marine engineer of the University of Glasgow, began to make experiments in the same direction. His first machine was called the *Bat*; with the experience gained he built a second one called the *Gull*; and then one called the *Hawk*. With all these he succeeded in making flights nearly as long as those of Lilienthal, but lost his life by an accident in 1899.

It is rather important to notice that both Lilienthal and Pilcher made their flights against the wind. The aviator, by running forward or jumping, caused the wind to blow against the curved under-surface of the planes, and lift the machine while it still had some way on it. The flight then continued with a slightly undulating motion, the machine falling steadily on the whole until the end. In order to secure lift, the air must move rapidly past the planes. As we shall see later, this condition can be secured just as well by propelling the machine forward in still air, or even in the direction of the wind itself provided that the velocity of the machine is greater than that of the wind.

There will, perhaps, always be disputes as to the inventors of flying machines, but nothing can rob the brothers Wilbur and Orville Wright of the credit due to them. They may not have been first, but, at any rate, when they appeared in public they were able to do all that they claimed to do. Moreover, they took the trouble to read everything that had been written on the subject, and they went to work with a systematic thoroughness that was bound to succeed.

The brothers were cycle mechanics. It was the death of Lilienthal in 1896 that first drew their attention to the problem of aerial flight. They soon saw that there were two ways of approaching it. On the one hand, Sir Hiram Maxim and Professor Langley were trying to drive a machine through the air at such a speed as to enable it to rise from the ground; on the other hand, Lilienthal, Pilcher, Chanute, and others had been learning how to control such a machine by experiments in gliding.

Professor Langley's experiments, carried out at the Smithsonian Institution, were remarkable for their number, patience, and accuracy. He fixed a plane on a long arm which rotated at high speed, and he measured the varying pressure on its surface. Having obtained information that enabled him to calculate the proper size of the planes for a given weight, he set to work to design a steam engine that would propel the planes through the air at such a speed that the weight of the engine and boiler would be supported. All this was done on a model scale; after many failures, the aeroplane was launched in the air from a boat on the River Potomac, and glided along for a minute and a half, at the end of which time the fuel and water were exhausted.

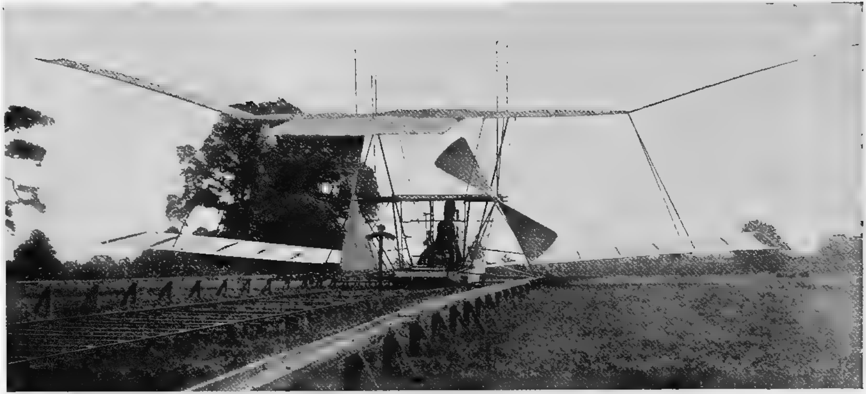
The next step was to make a machine on a larger scale, and here unforeseen difficulties cropped up. The machine was made, altered, and remade, but Langley could not get it to fly. It is interesting, however, to note that in 1914 the same machine was used successfully, a fact that shows that Langley was correct in his design, but possibly lacking in experience of control, which others had secured by practice in gliding.

Sir Hiram Maxim, the inventor of the "Maxim" Gun, was an inventive genius. An American by birth, he lived in England for many years, and his experiments were conducted in this country. His machine was on a larger scale than anything that had been attempted before; it weighed nearly 4 tons, and was driven by engines of 360 horse-power. It ran on wheels that were enclosed between upper and lower rails, so that, though it could rise off the lower ones, the upper rails prevented it from breaking away altogether. As a matter of fact, on one occasion the machine so strained the upper rail as to break it.

The brothers Wright were convinced that the first thing to do was to learn how to control a machine and then to make a motor to drive it. Some preliminary calculations showed them that with a wind velocity of eighteen miles an hour, an area of 200 square feet should be enough to support a man. Their idea was to make the machine captive by a rope, so that it could rise only a few feet from the ground, and to practise controlling it by the hour ; though they were not able to carry out their full intentions, they managed to obtain a great deal more practice than any of their forerunners.

In order to keep down the size and still have a large surface, the machine was made with two planes one above the other. In his later experiments Lilienthal had adopted this plan, and Chanute had also used it. But, whereas in previous gliders the man hung on to the machine with his body vertical, in the Wrights' machine the man lay at full length on the lower plane, having his hands free for steering or otherwise controlling it.

In the summer of 1900 the machine was taken for trial to a place called Kitty Hawk in North Carolina, a strip of land between Albemarle Sound and the Atlantic. It had only 165 square feet of lifting surface owing to the difficulties of obtaining material for a larger one. The wind varied in velocity from 14 to 30 miles an hour, and many tests were made. Sometimes one of the brothers took his place on the machine ; at others it was flown as a kite, and controlled by light cords. After some experience, actual tests of lift and drift were made, the results obtained being of great value, because the



MAXIM FLYING MACHINE ON THE EXPERIMENTAL TRACK.

drift or pull on the machine at rest represents the power required to drive it in still air at the velocity of the wind at the time of measurement.

In 1901 a new machine was made, having planes of rather greater curvature with an area of 308 square feet. This had to be modified several times, but the brothers soon made glides of more than 300 feet. Returning to the attack in 1902, they used a third machine, which made 1,000 glides without once causing injury to the pilot, and only on one occasion coming to grief itself. Meanwhile, the experimenters kept up their kite trials, even with the large machine, and they made many valuable measurements.

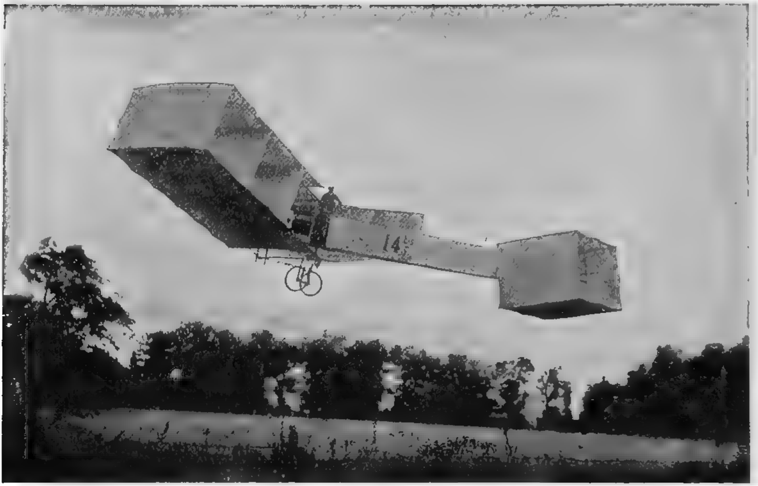
The next step was to propel the planes by power. An engine was constructed for the purpose in 1903, and actual flights were made in December. The first lasted twelve, and the fourth fifty-seven seconds. Nothing daunted, they made fresh attempts in the following spring near Dayton, Ohio, and continued them in 1905, Then the length of flight was increased to 24 miles and the duration to over thirty-six minutes. The chief troubles were met with in the motor, but many mishaps showed that there was much to be learned in the management of the machine itself, especially when making a turn. But the five years of assiduous practice had ended in success; and when the brothers are next heard of it is in France, where a greater popular interest in the subject, and greater faith in the flying men, had led to remarkable developments.

France, you will remember, is the country in which the balloon was invented, the country in which the greatest use of balloons in warfare has been made, the country that holds the record for the longest balloon voyage. Perhaps no country in the world followed the experiments of Lilienthal with so much interest. In the success which attended the efforts of so many other men, one of the early pioneers has very nearly been forgotten. Clément Ader was an engineer by profession, and was early attracted by the problem of flight. In order to study the flight of such large birds as vultures, he went to Algeria, disguised himself as an Arab, and penetrated into the interior of Northern Africa. On his return, he constructed in 1897 a large model of a bird with spreading wings that measured 54 feet from tip to tip. It had two propellers driven by a steam engine. The wings were flexible, and capable of being bent up or down at the will of the operator. Along the ground the machine ran at a speed of 36 miles an hour, and when it rose it made a flight of 300 yards.

Having spent more than £25,000 upon his invention, he offered it to the French Government. For a time there appeared to be some likelihood of their taking it up, and they bound him to secrecy. But, ultimately, Ader was thrown over, and this fact prevented him from obtaining private support. Eleven years later his machine was exhibited side by side with others which, under happier circumstances, had proved aerial flight to be possible.

In spite of Ader's failure—for so it was understood to be at the time—others were at work. In 1898 Captain Ferber began to practise gliding with a machine similar to that of Lilienthal, and later with a "biplane" like that used by the brothers Wright. He soon acquired skill in managing it, and proposed to fit it with a motor; but the French War Office gave him no support, and his experiments were brought to a close.

Another Frenchman, named Archdeacon, became interested in the matter. He had a biplane made which was towed along by a motor-car, or by a boat on the Seine, and was found to be quite capable of bearing a man, though in the latter case he was liable to get a ducking. By this time, however, the Wrights had solved the problem, and another aviator—perhaps the most remarkable of them all—had entered the field.



SANTOS-DUMONT'S FLYING MACHINE.

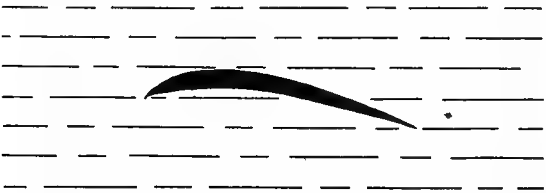
Albert Santos-Dumont was a wealthy young Brazilian, settled in Paris, who had had considerable experience in ballooning, and had constructed several airships to which reference is made in another chapter. In 1906, and in complete ignorance of the activities of the brothers Wright, he constructed several aeroplanes. The first one, which had an area of 237 square feet, came to grief. The next was somewhat larger, and with it he made a flight of 200 feet—with the exception of Ader's, the first flight in Europe. The great difficulty was to find a sufficiently powerful and sufficiently light motor, but these were improving, and when one of fifty horse-power was fitted to the machine a flight of nearly 700 feet was made.

From this point onwards the story of aviation is one long record of success. The flights were at first short—hardly more than hops off the ground. Man after man lost his life, but daily the number of aviators grew. The great ocean of air had hitherto been explored only by balloons, which travelled with the current, but these new machines were driven against the wind and the rough storm wherever the aviator willed. Frail things of wood or canvas with strengthening wires of steel, driven by motors of 40, 50, 80, or 100 horse-power, of extraordinary lightness, were to be seen flitting across the sky. Long journeys and daring flights were undertaken ; but before we consider these, let us see how the machines are constructed, and examine the way in which they are controlled.

CHAPTER XVI.

The Construction of Aeroplanes.

AEROPLANES are of three kinds—monoplanes, having one pair of wings ; biplanes, having two pairs ; and, less frequently, triplanes, having three pairs of wings. The monoplanes are based upon the gliders of Lilienthal and Pilcher, and the latter two types upon the gliders of Wilbur and Orville Wright. Between the wings, and at right angles to them, is the long, boat-shaped body, called the *fuselage*. This was originally nothing more than an open framework carrying the tail and providing space for the aviator and his engine. Underneath the fuselage is a framework, called the *landing chassis.* It is provided with wheels, on which the machine runs before rising into the air, and on which it comes to rest at the end of a flight. The propeller is always in the front of a monoplane; a biplane or triplane may have the propeller either in front or behind. In the former case the aeroplane is called a *tractor,* biplane or triplane, because it is drawn along rather than propelled. A screw, of course, could be placed at the bow of a ship, but it would be more liable to damage in that position. Since an aeroplane settles down on the ground on its wheeled carriage, the same risk of damage does not arise. A monoplane carries only one screw, but a biplane may have one or two.



SECTION OF AEROPLANE WING IN RELATION TO HORIZONTAL AIR CURRENTS.

The wings are made of a light, but strong framework of wood, over which is stretched tightly a thin fabric, varnished with a special composition, called dope, to render it waterproof. Light as they are, some support is necessary, and in the monoplane this is supplied by steel wires leading from the edges and tips to rods which are part of the central framework. The wings of a biplane or triplane are held together by stiff rods, made as thin as possible in order to reduce air-resistance. The amount of resistance that the air offers even to a wire is surprising, and the wooden struts are oval in section with sharp front and back edges, like a ship or a fish without a tail.

THE GOUPY BIPLANE—AN EARLY TYPE OF MACHINE.

The exact shape, curvature, and dimensions of the wings are the result of many experiments. In this matter the builders of aeroplanes have been guided to some extent by the wings of birds. One of the most important things to determine was the ratio of the length from tip to tip to the depth from front to back, called the *aspect* *ratio.* In birds this varies from 14 to 1 in the albatross to 4 to 1 in the lark. The aspect ratio of aeroplane wings is usually about 5 to 1. The figure shows a section of a typical wing: the reader will notice that it is built more strongly towards the front, for it is there that the lifting force of the air is mainly exerted. The shape of the rest is such as to allow the air to flow past with the least resistance.

The monoplane has, from the beginning, been provided with a fuselage, which at first consisted of a light, open framework. Modern machines, however, have this closed in with a light material, so as to form a boat-shaped body. The earlier biplanes had no fuselage, in the ordinary sense of the term. The tail was carried by light rods stretching out backwards from the main planes, and the aviator sat in a seat on the front edge of the lower plane. Here he was exposed to the wind and weather, with the danger of being pitched out if the aeroplane came down too heavily. The body of a biplane is now generally enclosed—in fact, several makers now produce machines in which the body contains a cabin, fitted with celluloid windows, and entered from a door in the side.

The early aviators perhaps found more difficulty in landing safely than in rising from the ground; for, unless the machine has some "way" upon it, it drops suddenly, and it is difficult to control exactly the speed and angle of flight as the ground is approached. Not infrequently a successful flight was concluded by the machine being broken or by injury to the pilot. All sorts of ingenious contrivances were made to prevent shock. One of the most interesting was that of Henry Farman. The wheels were fitted to vertical rods passing through the sockets in the landing carriage or chassis. These rods were held down by strong rubber bands attached to the framework and the tips of the wheel rods. When the aeroplane alighted, the wheel rods were forced upwards, stretching the rubber, and allowing the machine to fall gently.

The need for a contrivance of this sort will be understood when you realise that an aeroplane, fully loaded, weighs from half-a-ton to a ton and a half or more. Such a weight falling a distance of only two or three feet will produce a nasty bump. The beautiful landings now effected are the result of constant practice, and skill has been attained only after many failures.

FARMAN MACHINE IN FLIGHT.

The aeroplane is steered by means of a rudder. This is a small vertical plane situated at the end of the body, or on long rods stretching backwards from the main planes. It forms the tail, and the whole, or a portion of it, is hinged so that it can be turned by wires attached to a lever in front of the pilot's seat. The direction of the machine can thus be controlled just as in the case of a ship.

There are, however, several details connected with the control of an aeroplane that are unnecessary in the case of a ship. The ship is lighter than an equal volume of water, but the aeroplane is heavier than the air it displaces. If the cargo of a ship is properly distributed the vessel preserves an even keel. The aeroplane, on the other hand, tends to roll to a far greater extent, and, if the tilt forwards, backwards, or sideways, becomes too large, the machine glides down helplessly to the ground. In other words, it is not automatically stable. The more recent machines can often be driven for an hour without the pilot having to touch the control lever.

An aeroplane is prevented from going head downwards by a horizontal plane in the tail. This is set at a smaller angle to the horizontal than the main planes. Suppose the machine shows a tendency to dive. Before it has turned very far, the horizontal tail comes into a position in which the pressure of the air acts upon its upper surface, and this causes the head to come up again. If the machine rears up at the head the pressure on the under surface of the horizontal tail rises more rapidly than that on the main planes, and this brings the head down and the tail up.

These actions take place, of course, only when the machine is going at a good speed, for it is upon the speed that the pressure on the planes depends. If a sudden gust of wind is met with, which reduces the speed, or if a corner is being turned, there is a greater tendency for a slip to occur, and a dive head first or tail first may take place.

Some of the earlier biplanes were modelled on the Wright gliders, and did not have a movable horizontal plane at the tail. Instead, they had a small horizontal plane called an *elevator*, mounted well in front of the machine. This could be twisted about a horizontal axis, and acted like a horizontal rudder in causing the machine to ascend and descend.

Let us glance now at the means of securing stability in a sideways direction. If a side wind catches the aeroplane, it acts most strongly on the near wing, and some method is wanted of reducing the pressure on this and increasing it on the other wing. It will be clear to you that the upward pressure on a plane is least when the plane is horizontal, and increases as the angle of the plane to the horizontal increases, so that what is required is an alteration of the angle of the wings, which can be

A "BANTAM" AEROPLANE IN FRONT OF A GRAHAME-WHITE "BUS" FOR CARRYING PASSENGERS.

effected at once by the pilot when he feels the machine heeling over.

In monoplanes the wings can be warped along the back edges near to the tips, by pulling a lever. The rising plane is warped upwards so as to reduce the pressure upon it, and the falling wing is warped downwards so as to receive greater pressure. The upper plane of a biplane has two portions on the back edge near the tips provided with hinges, so that they can be raised or lowered. These are called *ailerons*, and the wires attached to them are so connected with the control lever that when one moves upwards the other moves downwards.

If you think for a moment what the pilot has to do you will see that he is a busy man. For, in addition to looking after the engine, and steering, he has to manage the elevator or lifting tail, and correct in an instant any tendency to tip sideways. Many of the first aviators were men who had been racing motorists, and were accustomed to the management of an engine, and to high speeds. They had acquired a delicacy of touch that the ordinary man does not possess, and they were consequently able to anticipate almost every movement of the machine. It was dangerous work, but the beautiful smoothness of motion and the joy of conquest made them treat risks lightly.

CHAPTER XVII.

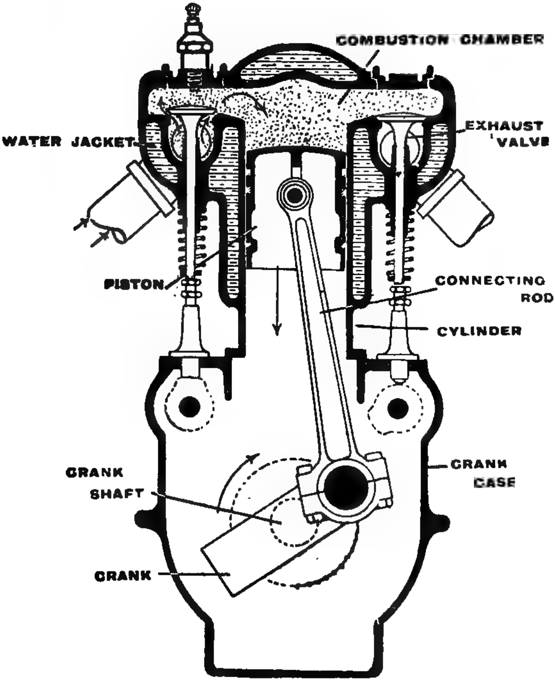
Aeroplane Engines.

THE method of constructing an aeroplane has been known for more than 100 years. Sir George Cayley showed how it could be done in the case of a monoplane in 1809. Again, in 1866, Mr. F. H. Wenham explained how a machine might have several planes. He pointed out that large birds could skim close to the surface of water without causing a ripple, a fact which showed that only a thin layer of the air was concerned in their support. But, though Lilienthal and others had shown that gliding was possible, the aeroplane waited for a light, powerful engine to drive it.

A steam-engine was out of the question, because, though a light engine can be made, the boiler, fuel, and water weigh a great deal. You will remember that Langley's model, on that account, could only fly for a minute and a half, in which time it covered half-a-mile. Similarly, an electric motor requires a battery, and this is tremendously heavy for the power it supplies. But, in 1884, a German named Gottlieb Daimler invented the petrol motor, which, by the time that gliding experiments were complete, had come into regular use on motor cars.

A petrol motor is quite easy to understand. Petrol is a liquid obtained from petroleum ; it readily passes into vapour, and both liquid and vapour are very easily ignited. If you look at the illustration you will see that the engine consists of a cylinder (of which there may be one or several) fitted with a piston, which is connected to a crank-shaft. At the end of the piston are two valves, one opening inwards and one outwards. The first is for the admission of petrol vapour and air, and the second for the escape of the exhaust gases. Each valve is controlled from the crank-shaft and caused to open and close just at the right moment.

If the crank-shaft is given a few turns by hand, the first outward stroke of the piston draws into the cylinder a charge of petrol vapour and air. Before entering the cylinder the petrol comes from a jet, which breaks it up into a spray and enables it to mix thoroughly with the air. The small vessel in which this takes place is called a carburetter. The return stroke of the piston compresses this mixture, and when it reaches its farthest point an electric spark is produced at the sparking plug, which causes an explosion. The piston is now driven out with a rush, causing the crank-shaft to turn. Just as the piston comes back again the exhaust valve opens, and the waste gases are swept out.



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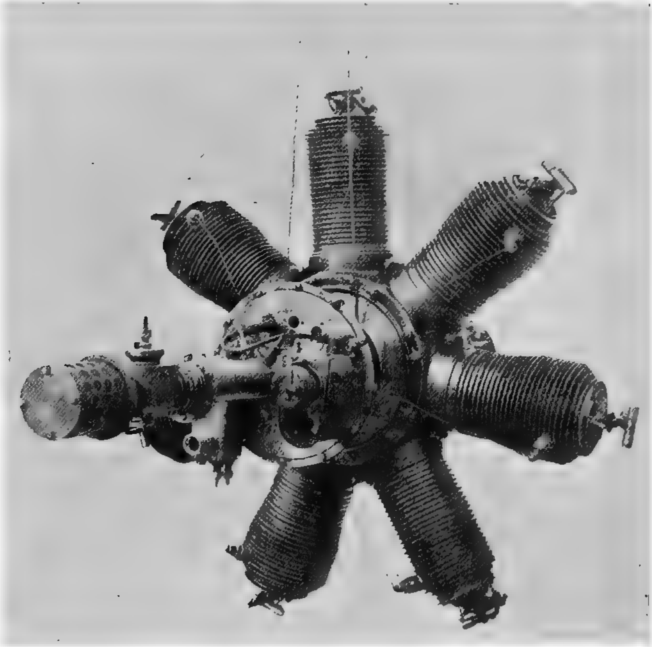
SECTION OF A PETROL MOTOR.

The explosions in the cylinder cause it to become hot, so the cylinders of most engines are surrounded with a water-jacket to prevent the piston from jamming. If there is no water-jacket the outside of the cylinder has a number of thin ribs, which expose a large surface to the air and assist in cooling it. The carburetter, on the other hand, needs to be kept warm to encourage the petrol to pass into vapour. It is therefore often surrounded with a jacket through which either hot



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GNOME AERO ENGINE.

water from the cylinder jacket, or hot gases from the exhaust, circulate.

This, in its broad outlines, is the way in which petrol engines work, but there are many details into which we cannot enter here. The cylinders are arranged in all sorts of ways. Sometimes they are in a long row of two, four, or six; sometimes they are arranged in pairs, making a " V " with each other, and then there often are twelve cylinders; and sometimes they are arranged in a circle round the crank-shaft. Some engines, of which the Gnome is an example, are quite different from the others, and, in fact, from any engine which had been made before. The crank-shaft is fixed—that is to say, it does not rotate. The seven cylinders are mounted in a circle all pointing towards the centre of the shaft, and are fixed on a tube surrounding the shaft. When the engine is working the cylinders spin round, while the crank remains still.

If you think over this carefully you will understand what is happening. The engine works by the pistons moving backwards and forwards in the cylinders. If the crank is fixed and the cylinders revolve round the centre of the shaft, they will sometimes be nearer to and sometimes farther away from the crank. The distance of the pistons from the crank will remain fixed, because the rods which connect them to it are unalterable in length; but the cylinders will slide on and off the pistons as they spin round. This is one of the most wonderful engines in the world, and most of the early successes in aviation were obtained by its aid.

When engines were first used for aeroplanes there was a good deal of doubt as to the power required. That used by the Wrights was of 25 horse-power. Mr. A. V. Roe built a triplane in 1909, on which he made short flights with an engine of only 9 horse-power—the smallest power with which a flight has ever been made. But at the first Aviation Meeting at Rheims men began to use engines of 50 horse-power and to obtain speeds of 45 miles an hour. Nowadays machines have engines of from 50 to 500 horse-power. With these, speeds of more than 150 miles an hour are attained.

CHAPTER XVIII.

The Aeroplane in War.

No sooner had the pioneers shown that flying was a reality and not a dream, than the nations of the world, ever ready to seize upon a new instrument of war, added Flying Corps to their armies. The time is long past when soldiers march in dense masses to engage in hand to hand conflict, and the battles of the present day are conducted by men hiding in trenches or creeping from cover to cover, while big guns thunder forth from some cunningly concealed position. With the great range of modern artillery a captive balloon is of smaller value and cannot approach enemy positions so closely as to be of much service. But the aeroplane, circling overhead with a velocity of 70 or 80 miles an hour at a height of from 6,000 to 10,000 feet, can spy out the positions of men and guns with wonderful precision. For scouting it has introduced an altogether new element into warfare.

At most of the military aerodromes in Great Britain, and to a still greater extent in France, flying takes place daily. From 1911 to 1914, military trials were held annually on Salisbury Plain. The machines—both monoplanes and biplanes—were tested in a number of ways, but chiefly for speed, reliability, quickness of ascent, and length of glide from a given height with the engine stopped. It will be interesting to consider why these particular matters are important in a military aeroplane.

The question of reliability can be passed over at once. An engine which is always liable to get out of order, or a framework liable to breakage, is obviously useless. In 1911 the engines were required to run for 24 hours continuously, and as only one of those entered succeeded in doing this, you will realise how severe was the test. Speed again is essential when the lives of the pilot and his companion (all military aeroplanes carry a pilot and an observer), together with the valuable information they have acquired, depend upon a swift and safe return. But this is not the sole condition. At high speeds—say 100 to 150 miles an hour—it is difficult to make minute observations, and for this purpose a slower speed is essential. At the trials in 1912 the late Mr. S. F. Cody was able to vary his speed from 72 to 45 miles an hour without appreciably altering his level.

If, again, the aviator has landed for any reason, it is essential that he should be able to climb rapidly out of reach of gun fire, and the Hanriot monoplane at these trials rose at the rate of 360 feet a minute. This rate has since been exceeded.

The necessity for a test of the length of a long glide downwards arises from the fact that the engine may stop or the petrol tank be pierced by a bullet when the aviator is over or near the enemy's position. The mere stopping of the engine is of little consequence, because by keeping the machine at a proper angle it will glide steadily down to the ground. Such an accident has occurred several times without any harm resulting to the aviator. But this has been in time of peace, and in war-time safety includes not only a slow and easy descent, but a long descent. In the military trials of 1912,

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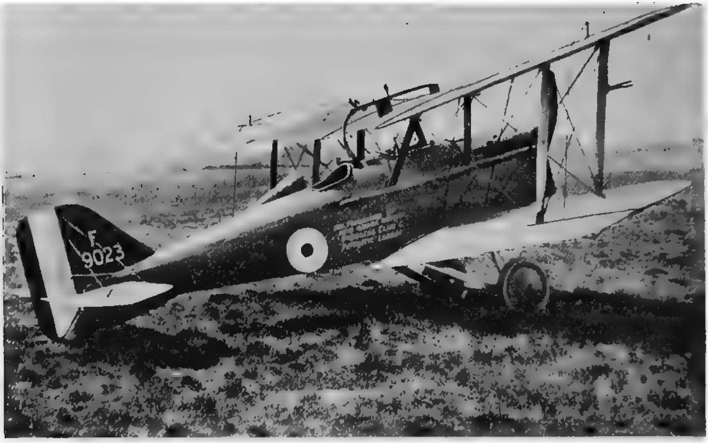
AEROPLANE SCOUTS.

already referred to, the engine of Mr. Cody's biplane was stopped when he was 1,000 feet from the ground, and he made a glide which brought him to earth 6,000 feet away. In a similar way, the Hanriot monoplane, the engine of which was stopped at an altitude of 1,300 feet, executed a glide of 8,000 feet in its descent.



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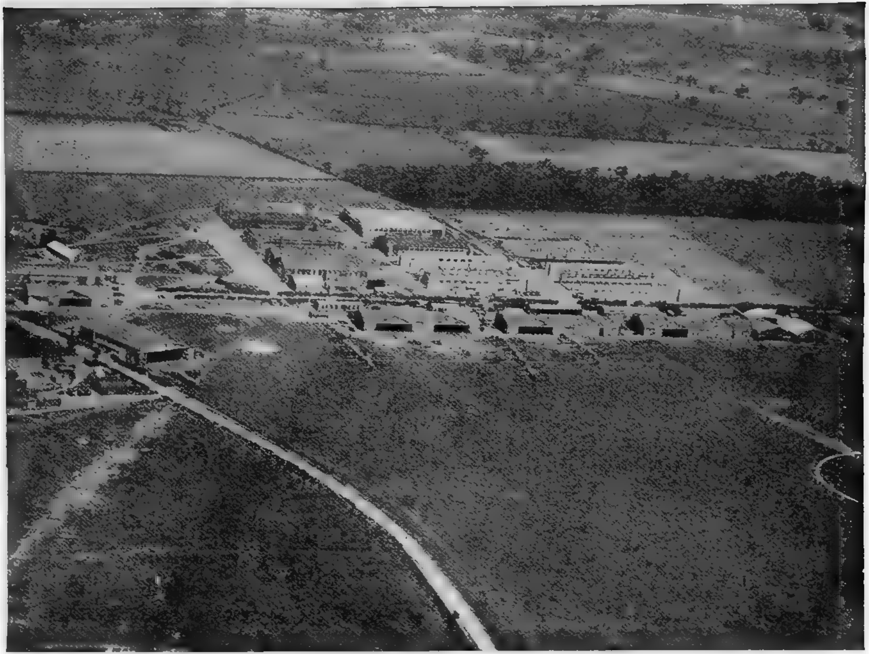
AN AEROPLANE SCOUT.

But before 1914 no one could have foretold the influence that the aeroplane would have in war and the variety of purposes which it would be called upon to serve. During the war vast fleets of machines were built, and different forms were developed for observing, fighting, and bombing. The machines used for observing were fitted with cameras, and from the photographs taken by these,



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AERIAL PHOTOGRAPH OF AN AERODROME, SHOWING A SQUADRON OF AEROPLANES PREPARING FOR DUTY.

maps of the enemy's position were made. When these machines were at work they were often attended by fighting machines, to protect them from attacks by enemy aircraft. Frequently the fighting machines went out in groups and regular battles with similar enemy groups took place in mid-air. At other times the fighting machines went out singly to destroy the observation balloons from which the fire of the big guns was directed. To effect this they fired an incendiary shell like a rocket, which set the balloons on fire, while the observer in the balloon escaped, if he was quick enough, in a parachute.

The bombing machines carried bombs containing many pounds of high explosive, which were used to destroy the enemy's aeroplane sheds, ammunition dumps, railways, and to attack columns of men on the march. In the later years of the war distant towns were bombed, and long journeys had to be made through the night. But with his instruments in front of him, illuminated by a small electric lamp, the pilot can steer his craft as surely as a captain can navigate his ship, though an ocean of darkness surround him.

Of course, every increase in the power of the aeroplane for attack was followed closely by improved means of defence. The speed of the fighting machines was increased, and they were so designed that more rapid twists and turns could be made. Anti-aircraft guns, some of which were fixed, and others mounted on motor-cars, were constructed to throw a shell almost as high as an aeroplane could ascend. At night the aeroplane was detected by powerful search-lights. In order to get the range, shells were fired which left a track of smoke by day and a trace of fire by night. And when the range was found the enemy machine was soon surrounded by little white puffs of bursting shrapnel.

Thus by more speedy and easily-steered aeroplanes for defence, by powerful search-lights which revealed them at night, and by means of more powerful guns with improved methods of finding the range, many attacks of enemy machines upon our own towns were defeated and brought to nought.

CHAPTER XIX.

Famous Flights.

THE year 1906 saw many men in England, France, and America learning to fly. The earlier flights were not of long duration, and did not give much promise of the future triumphs. Thus, Henry Farman was satisfied with a flight of 300 yards, and Delagrange succeeded in remaining in the air for 9 minutes. The movement in France encouraged Wilbur Wright to bring his machine from the States. There was some delay with his engine, which refused to work properly; but once this defect was overcome, he showed what could be done by remaining in the air for two hours, and by carrying a passenger to a height of 400 feet. Then man realized that aerial navigation was really possible.

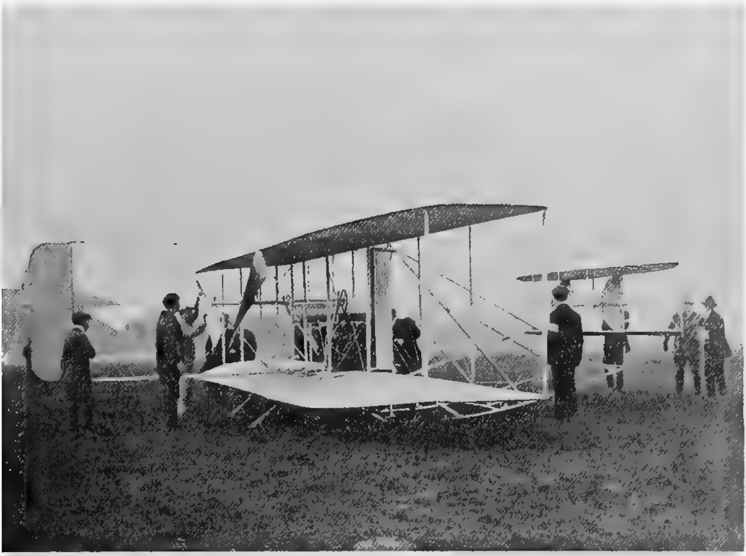
The year 1907, however, marks the beginning of the age of mechanical flight. An aviation meeting at Rheims attracted attention all over the world. Competitions were held for speed and height. The first was won by Glenn H. Curtiss, an American, with a speed of 47 miles an hour, while Hubert Latham won the height test by rising to over 500 feet. How small these achievements were compared with later ones will appear presently. Another meeting was held at Blackpool in the same year, and was chiefly remarkable for a daring flight by Latham who went up in a gale of wind. At times, when turning a corner in the teeth of the wind, his machine seemed to stand still.

Apart from these two meetings aviators were busy in many places. Wilbur Wright took up a passenger and remained in the air for an hour and a half, while Henry Farman flew for 4 hours and 17 minutes. All these attempts were made over a definite course, and though short flights were exciting enough, the journey round and round the course became tiresome to watch.

THE DELAGRANGE MACHINE IN FLIGHT.

But aviators were getting bolder. They were acquiring skill and confidence in the management of their machines, and their engines were becoming more reliable. Instead of flying round and round a course they began to strike out across country. By experience they had found that by rising to a considerable height the air was quieter and less treacherous; so they rose until they appeared to be mere specks in the sky.

Latham made two attempts to cross the English Channel, but both were unsuccessful. Between the first and second, however, Blériot, on a monoplane of his own design, accomplished the journey in less than 40 minutes. A prize of £10,000 offered by the *Daily Mail* for a flight from London to Manchester attracted a good deal of attention. Grahame White made two plucky attempts, but was twice pulled up by treacherous winds when crossing the valley of the Trent. Louis Paulhan, a young



A WRIGHT AEROPLANE.

French mechanic, however, succeeded in accomplishing the journey of 183 miles with the one stop that was permitted.

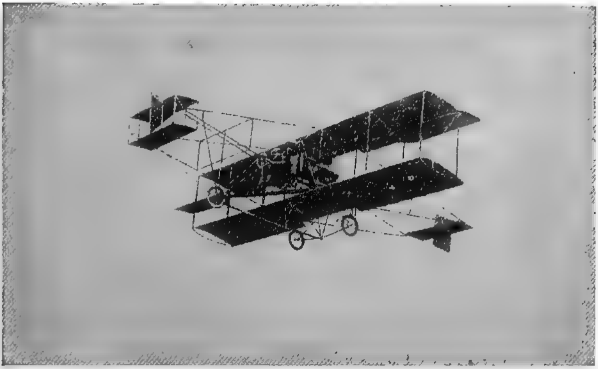
The Hon. C. S. Rolls, who had attained fame as a motorist, took to aviation, and flew from Dover to Calais and back without coming to the ground. Shortly afterwards Robert Loraine, the well-known actor, flew from Holyhead to Ireland across 52 miles of sea. Nor were the Americans idle, for Glenn H. Curtiss, who had won the speed prize at Rheims in the previous year, flew from Albany to New York, a distance of 150 miles.

BLERIOT'S MACHINE.

M. Bleriot was the first aeronaut to cross the English Channel on an aeroplane.

You will remember that the height prize at the first Rheims meeting had been won by an altitude of 500 feet. Now look at the progress of a single year. Armstrong Drexel, a wealthy young American who was flying at Lanark, rose to a height of 6,000 feet. Still, men were not satisfied. Within a few months other aviators rose 8,469 feet, and 9,174 feet. Then Drexel rose to 9,450 feet, but was again beaten by altitudes of 9,714 feet and 10,746 feet. This was only in 1909, and since then the record has been more than doubled. A machine heavier than air and driven by a petrol engine has thus been able to rise to a height of nearly four miles above the surface of the earth.

Having achieved success, several of the pioneers who had escaped with their lives settled down as aeroplane makers or as instructors in flying. In 1910, therefore, there appeared a new group of men, who, however, proved to be not one whit less skilful or daring than those who had paved the way. Races of far greater length, with appropriate stops for replenishing the supply of petrol and obtaining rest, were arranged.



THE CURTISS MACHINE IN FLIGHT.

But at this stage the number of remarkable flights becomes bewildering, and nearly every day, certainly every week, saw a new triumph. One of the first races was a circuit of Great Britain—1,010 miles—in stages, the aviators landing at certain places for stated periods. Another was the circuit of Europe, a distance of 10,030 miles, and a third from Paris to Rome, a distance of 815 miles. All three were won by Lieutenant Conneau of the French Navy. The race from Paris to Madrid, a distance of 874 miles, was won by Védrines, who at a later date won the Gordon Bennett cup in America with a speed of 105 miles an hour.

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COMMERCIAL TRANSPORT AEROPLANE IN FLIGHT.

Another daring flight was that over the Alps, starting from Brigue in Switzerland. This involved an altitude greater than any that had been attempted before, and was particularly dangerous because of the treacherous air-currents in mountainous regions. Nevertheless about a dozen men entered the contest, and Chavez alone succeeded. Unfortunately, at the end of the journey he had a bad fall, and died in hospital a few days later. So great was the public interest in this daring exploit that as he passed over the Italian side a train was stopped so that the passengers could see him.

Mountains of less height than the Alps have proved no barrier. In the same year in which Chavez came to grief, another airman flew over the Pyrenees from San Sebastian to Biarritz. Aviators now fly so high that they are well out of reach of the changing currents met with near the ground. Instead of the 400 feet at which people were astonished at the Rheims meeting, a long distance flight is rarely made at lower altitudes than 1,000 feet, and from 5,000 to 10,000 feet is frequently attained. Within a few years what was a height record has become a common flying level.

At such a distance from the ground an immense tract of country is seen, and the appearance of towns, villages, and land-marks is so different that it is not easy to find one's way. The danger of this is, of course, much greater at night or during foggy weather, and if a machine is above the clouds, the sun or stars are an aviator's only means of steering. When Blériot flew across the Channel he took no compass, and for a time he was out of sight of land and water, alone in space with nothing to point the way.

Balloonists have often described the intense solitude of the upper atmosphere, with the clouds below them boiling up in ceaseless but silent turmoil. Overhead the sky may be studded with innumerable stars in a background of inky blackness, or a silvery moon may light up the clouds, casting strange fantastic shadows on the denser masses below.

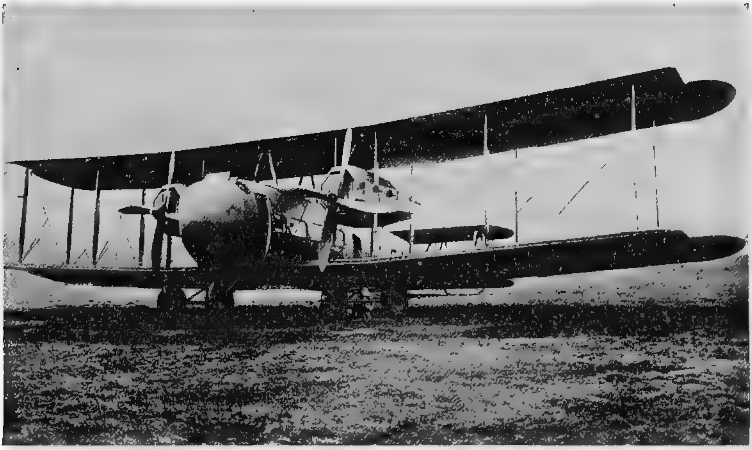
In the year before the War Védrines flew from Paris to Cairo, and talked of continuing his journey to the Cape; and so great had confidence in the new mode of locomotion become that the *Daily Mail* offered a prize of £10,000 for a flight across the Atlantic. Gustav Hamel was to have started from Ireland on a Handyside machine, and Lieut. Porte, R.N., from America on a Curtiss biplane. Before the preparations were complete, however, Hamel was lost in crossing the Channel, and Lieut. Porte had to postpone his attempt.

After the Armistice, interest in the contest was revived, and a number of airmen gathered in Newfoundland with their machines and awaited favourable weather. The first to get away, on May 16th, were four American Naval aeroplanes. They did not attempt a direct flight but a series of short steps. Only one, piloted by Lieut. Commander Read, succeeded in completing the journey, landing at Plymouth on 31st May, after stops at Hosta (Azores), Ponta Delgada, Lisbon, and Ferrol. The longest step was 1,381 miles, from Trepasssey in Newfoundland to Hosta.

Two days after Lieut. Commander Read started, on 18th May, H. G. Hawker and Commander Grieve left St. John's, Newfoundland, and all trace of them was lost until 25th May. When a thousand miles from Newfoundland and only 750 miles from the Irish coast they had been obliged to descend, and were picked up by the steamer *Mary*. It was not until they were transferred from the *Mary* to H.M.S. *Revenge* a week after they started that news of their whereabouts could be sent, and in the meantime they had been given up as lost. The welcome which they received was as great as though they had been completely successful.

Meantime, Captain John Alcock and Lieut. Arthur

Whitten Brown, who had arrived late at St. John's, waited for a favourable opportunity. Their machine was a Vickers-Vimy bombing machine, which had been altered at short notice for the Transatlantic flight. It was fitted with Rolls-Royce engines, and carried 865 gallons of petrol—sufficient for a journey of 2,440 miles.



VICKERS-VIMY AEROPLANE.

They left St. John's at 5.28 p.m. on 14th June, and landed at Clifden, Ireland, at 9.25 a.m. The actual time of the crossing was 15 hours 57 minutes. Most of the time they did not know where they were. They hardly ever saw the sun, moon, or stars. Frequently they had to fly within 300 feet of the sea, and for four hours the machine was covered with frozen sleet. The wireless apparatus broke down half-an-hour after their leaving the Newfoundland coast, and they were unable to signal their position. Finally they landed in a bog, and the machine buried its nose in the ground. It was so far damaged that they could not continue their flight in it to London as they had hoped to do.

Those of us who do not fly cannot well imagine the sensation of speeding through the air at 120 miles an hour for sixteen hours, and being unable to see more than a few yards ahead, astern, above, below, or on either side. Captain Alcock stated that they accidentally made a spiral dive, and at one time they believed they were travelling upside down within 100 feet of the sea. He, himself, was dazed with the noise of the engine, and Lieut. Brown was dazed with the shock of landing. They received a wonderful welcome, and both men had the honour of knighthood conferred upon them by the King. Unfortunately, Sir John Alcock was killed in a flying accident a few months after his great triumph.

To understand the rapidity of improvement in flying as compared with the slow progress in gliding, it must be remembered that the total practice obtained by Lilienthal, for example, did not amount to more than a few minutes in a few years. But when men can remain in the air for hours at a time they soon acquire experience and a sensitiveness of touch that anticipates almost every alteration in the movement of the machine. If any evidence were needed on this point it would be provided by the feats of "Looping the Loop" which became common during the twelve months or so before the Great War. In the early days, men lost their lives by trying to perform tricks in the air. After many accidents they were more careful. The world was astonished, therefore, when, in 1914, two Frenchmen, Pegoud and Chantalupe, began to describe circles in which for a time they were head downwards. They were speedily followed by Hamel and B. C. Hucks, and the evolution was repeated so many

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AEROPLANE LOOPING THE LOOP—SHOWING THE POSITION JUST BEFORE TURNING ON TO ITS BACK.

times as to demonstrate the complete control over his machine possessed by the skilful pilot. Not content with being able to move in three directions like a fish in water, man after a few months' practice indulges in playful antics which have not entered the head of a fish after 10,000 years.

CHAPTER XX.

Airships.

THE power to make, ascend in, and manage a balloon were great feats. But was it likely that man would be satisfied with a vessel at the mercy of every wind that blew? Had he been satisfied 10,000 years before with the log of wood floating on the bosom of the river? Did he not make himself a paddle to master the current, and a sail to save labour? And was it possible that he, whose mechanical ingenuity had accomplished this and so much more, would be content to remain stationary in his power over the air when the naked and ignorant savage had made such advances in his power over the water? In these later days man takes greater leaps in knowledge and skill in a century than his primitive ancestors took in a thousand years.

A balloon that can be steered is called a *dirigible* balloon, the word "dirigible" meaning directable or steerable; and though a balloon can, as we have seen, be steered to a slight extent if a drag rope is attached, perfect control of direction is only possible with some form of propulsion, so that headway can be made even against the wind. Moreover, a dirigible balloon must have a different shape, the sphere being suitable only for drifting with the wind.

The balloon itself, you will remember, was invented only in 1793, and in the following year a Frenchman named Brinon proposed a cylindrical bag with conical ends, and with oars as a means of propulsion. A vessel of this kind was actually constructed and made a successful ascent on a calm day. About this time also, General Meusnier stated the general principles that must underlie the construction and management of dirigible balloons, and about them we shall have something to say presently. In those days, however, there were no light engines, and the action of the screw propeller was not fully understood, so that it was many years before a satisfactory airship could be built.

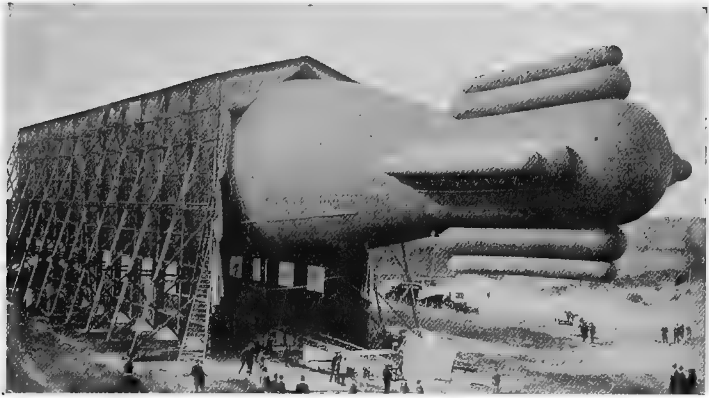
The truth of the statement in regard to the engines is proved by the fact that the next important attempt to solve the problem was in 1852, when Giffard, the well-known engineer, constructed an engine giving 5 horse-power and weighing 100 lb. His balloon was 144 feet long and 40 feet in diameter, with pointed ends. Its capacity was 90,000 cubic feet. If you compare this with the size of some of the ordinary balloons of the period, you will see that the capacity had to be very considerably increased to support the engine as well as the passengers and crew. The airship made several flights, and was found to be capable of a speed of five or six miles an hour independently of the wind. In a wind with a velocity greater than this, the airship would be swept along with it, so that it was of very little more value than a balloon.

But Giffard was not discouraged, and before his death in 1882 he constructed several more. The time, however, was not yet, and though he had made an important advance, years were yet to pass before real success was achieved. In these years men were not idle. A dirigible balloon was constructed by Paul Hänlein, a German, in 1872, and another by Dupuy de Lôme, a Frenchman, in the same year. The latter was propelled by screws driven by eight men working a sort of windlass. A little later two more Frenchmen, Gaston and Albert Tissandier, constructed one in which the motive power was electricity.

The greatest step was made in 1884 by Captain (now Colonel) Renard and Captain Krebs, of the French Army. Their balloon, called *La France,* made a number of voyages over Paris. This was the first airship that could really be navigated in ordinary winds and be brought back to its starting-point at the will of the pilot. On one occasion it attained a velocity of nearly 15 miles an hour. A large wooden screw-propeller was used, driven by an electric motor. The stoke-hole was covered with wire gauze, and the chimney was bent twice at right angles so that it pointed downwards to reduce the chance of sparks reaching the inflammable gas above. Still, it needed some pluck to go up in a balloon with an inflammable gas as a means of support, and a steam-engine as a means of propulsion.

All this had been no more than slow and dangerous experiment, and had merely shown that a dirigible was practicable. The real joy of triumph and the romance of aerial flight under the power of an engine and the control of a rudder were to be shared by a Brazilian and a German, who worked quite independently of each other, and on different lines. Santos-Dumont, who afterwards achieved success with heavier-than-air machines, and Count von Zeppelin, a German general, will always be remembered as the constructors of successful airships. But they began with the great advantage of 100 years of inherited experience, at a time when the first really light engine had been given to the world.

It is related of the great Sir Isaac Newton that he attributed his success to the fact that "he stood on other men's shoulders." The work that others had done before his time had not to be done over again; he could start from where they left off. So it is with all the great discoveries and inventions of the present day. Knowledge is heaped up higher and higher as the centuries roll by, and the men who are persevering enough to climb to the top of this heap are the men who add to its height, and are thus able to survey a wider and wider field.



AN EARLY TYPE OF AIRSHIP, THE "VILLE DE PARIS" OF THE FRENCH GOVERNMENT.

The earlier workers met with failure or, at most, partial success, not because they could not construct a balloon, but because the petrol motor was not known. But even in the construction of the balloon itself there were some facts that could be learned only by actual flight. It will not be without interest to see what some of these facts are.

CHAPTER XXI.

The Construction of Dirigible Balloons.

ONE of the earliest facts discovered in ballooning was the necessity of leaving the neck open, so that the gas within the bag could expand or contract with changes of temperature or pressure. There is thus no tendency for the bag to alter its shape. But, when a balloon is driven against the wind, the pressure on the front will immediately squeeze the gas out of the bag, if it is open, and that side will be forced into the shape of a cup; so, not only would the resistance to motion be enormously increased, but the loss of gas would rapidly affect the buoyancy. For that reason the bag of a dirigible balloon must be closed.

Now difficulties may arise from two other causes. If the balloon ascends too high, or if the temperature rises, the gas within will expand and the bag may burst. Again, if the temperature falls, the gas contracts and the bag becomes flat and loses its shape. When the shape goes, the resistance to motion increases, and the vessel will tend to drift before the wind. If the shape alters very much, some of the ropes holding the car will slip off and greater strain will be put on others.

The method of overcoming these dangers was pointed out by General Meusnier, to whom reference has already been made. This is to enclose the gas in a *ballonnet* (little balloon) inside the main envelope, and to pump air into the space between the two bags in order to keep the outer envelope fully extended. Or alternatively the light gas may occupy the principal space and air be forced in or allowed to pass out of a ballonnet.

It is necessary, of course, that the ship should float upon an even keel, especially if, owing to loss of gas, the envelope becomes at all flabby; for in that case there is liable to be a rush of gas to one end, and the balloon will rise with either its nose or its tail in the air. M. Santos-Dumont learned this by several exciting experiences that occurred towards the end of some of his journeys. He overcame it by placing unvarnished silk partitions in the bag. The gas was thus able to ooze through from one compartment to another, but could not flow with a rush to either end. An even more satisfactory plan is to have a number of compartments with a separate ballonnet in each.

As a balloon, however, is continually losing a little gas, as petrol is being used up in the engine, as ballast is thrown out in order to rise, and as other changes are taking place, which all tend to alter the distribution of the weight, it is still necessary to have some means of adjusting the level. Santos-Dumont's first plan was to suspend a sand bag from each end of the balloon. Either of these could be drawn in towards the car by means of a light cord, thus bringing a portion of the weight nearer to the centre.

His second method was more ingenious. From one end of the balloon hung a long rope, which was looped up to the car so that the free end hung vertically beneath. The weight at that end of the vessel could thus be increased or diminished by paying out more or less rope into the loop. In more recent airships a long keel runs from end to end, and a weight, sliding upon this, is used to keep the level.

The airship designer has other troubles to overcome. The car is suspended from the envelope by wire ropes, and this connection is flexible. If the screw is on a level with the car and is pushing, the balloon itself will lag behind, with the result that its nose rises in the air. It is, of course, impossible to mount the propeller at the back of the bag, but if this were done the nose of the balloon would point downwards. There is, in fact, only one line of action, somewhere between the two we have considered, along which a propeller will force the balloon in a horizontal direction ; and that position is equally impossible. So the screw is placed at the front or back of the car, and the tendency to elevate the nose of the airship corrected by two large planes (one on each side of the car), the angle of which to the horizontal can be adjusted. These enable the balloon to ascend, proceed on a horizontal keel, or descend, at will. They are called elevating planes.

Colonel Renard discovered, in the course of some calculations he was making, that if an airship is driven at more than a certain speed it will lose its stability and begin to wobble. The speed at which this takes place is much higher if the tail of the balloon carries a number of planes. All the airships, therefore, which are intended to travel rapidly are fitted with these *stabilising* planes, or in the earlier types with small pear-shaped ballonnets, which serve the same purpose.

Now, having seen the numerous details to which attention must be paid in the construction of an airship, we may turn to the exploits of Santos-Dumont and Zeppelin and the vessels they made.

CHAPTER XXII.

Santos-Dumont and Count Zeppelin.

In 1898, when Santos-Dumont gave orders for an airship to be built, people laughed at him. He had difficulty in persuading manufacturers to undertake the work, and ultimately he had to secure a workshop and have a great deal of it done under his own supervision. First, a 3½ horse-power motor was constructed, which weighed 66 lb. This was fixed to a motor-car and thoroughly tested in a race from Paris to Amsterdam. The envelope was made of Japanese silk, the lightest substance obtainable, though the makers said that it was not nearly strong enough for the purpose. It was 82½ feet long, 11⅓ feet in diameter, and possessed a capacity of 6,354 cubic feet. To maintain an even keel, two bags of ballast were used as described in the last chapter. Self-acting valves allowed gas to escape or air to enter, as the pressure or temperature varied.

A successful ascent was made on 20th Sept., 1898, from the Jardin d'Acclimatation in Paris. The airship rose gracefully over the surrounding trees and was steered in a wide curve over the city. Emboldened by success he rose higher; some of the gas was squeezed out; and, as he descended, the envelope became flabby and tended to double up. This lessened the tension on some of the cords and increased that on others, so that the car threatened to break away. Moreover, the buoyancy was now so far reduced that the descent became rapid. At that moment he spied some boys flying kites in the field below, and he called to them to seize the guide-rope hanging from the car and run with it against the wind. They obeyed readily, the rate of fall was lessened, and Santos-Dumont escaped without injury.

The second and third airships were built in 1899; a fourth in 1900, and a fifth in 1901. The second one collapsed during its first ascent, owing to the rain, which was falling at the time, cooling the gas and causing the envelope to fold up. In this state the wind caught it and tossed it into the trees, to the peril of the pilot. In the fifth he made an eventful voyage round the Eiffel Tower, but again had a remarkable escape from death. During the journey the balloon lost gas, altered its shape, and allowed some of the suspension wires to foul the propeller. When the engine was stopped, the balloon, falling all the time, was blown towards the Tower. One end of the balloon was empty and fluttered about in the wind, while the other end pointed towards the clouds. Ultimately the airship fell on the Hotel Trocadéro, with one end of the keel on the main roof and the other end on a lower one. The aeronaut was left suspended in mid-air between the two until a body of firemen came to liberate him from his dangerous position.

A sixth airship, built in 1901, was more successful, but even in this he had some exciting experiences. By this time, however, he had acquired greater skill and confidence, and was prepared to make flights anywhere. In 1902 he flew over the Bay of Monaco, and on one occasion had to drop quickly into the sea to avoid being driven on to the houses which line the shore.

In 1903 he set up the first regular airship station and kept three vessels. One of these was a "runabout" of only 7,770 cubic feet capacity, driven by a 3 horse-power motor, and capable of a speed of 12 miles an hour. With this he wandered about over Paris, on one occasion passing down the Champs Elysées on a level with the upper windows of the houses, and on another going home to lunch and anchoring his airship at his front door in the meantime. Having so far succeeded in his object he handed over his fleet to the French Government, "for use against any country except the two Americas," and turned his attention to the heavier-than-air machine about which you have read in a previous chapter.

While Santos-Dumont will always be remembered in the history of man's efforts to conquer the air, Ferdinand von Zeppelin will always be regarded as the man who rendered aerial navigation possible on a large scale. As a young man he joined a German volunteer corps which assisted the North in the American Civil War, and he made several ascents in a captive balloon. Returning to Germany, he was engaged in the wars against Austria in 1866 and against France in 1870, in both of which he gained distinction. After retiring from the Army, he devoted himself to the construction of airships, and came to be regarded to some extent as mad, and wholly as a nuisance.

After refusals of assistance from the War Office, and from wealthy men to whom he applied, he secured the friendship of King William of Würtemberg. In 1898 the construction of a balloon of a new type was commenced. To avoid the difficulty of loss of gas leading to loss of shape, Zeppelin determined to make his balloon rigid. It consisted of a long cylinder with pointed ends, constructed of a framework of aluminium rods. (This metal is less than half the weight of iron, and only $\frac{1}{3}$ the weight of copper, bulk for bulk, and it is fairly strong.) The framework was entirely covered with linen and silk, and had sixteen compartments each containing a gas-bag. It was 420 feet long and 38 feet in diameter.

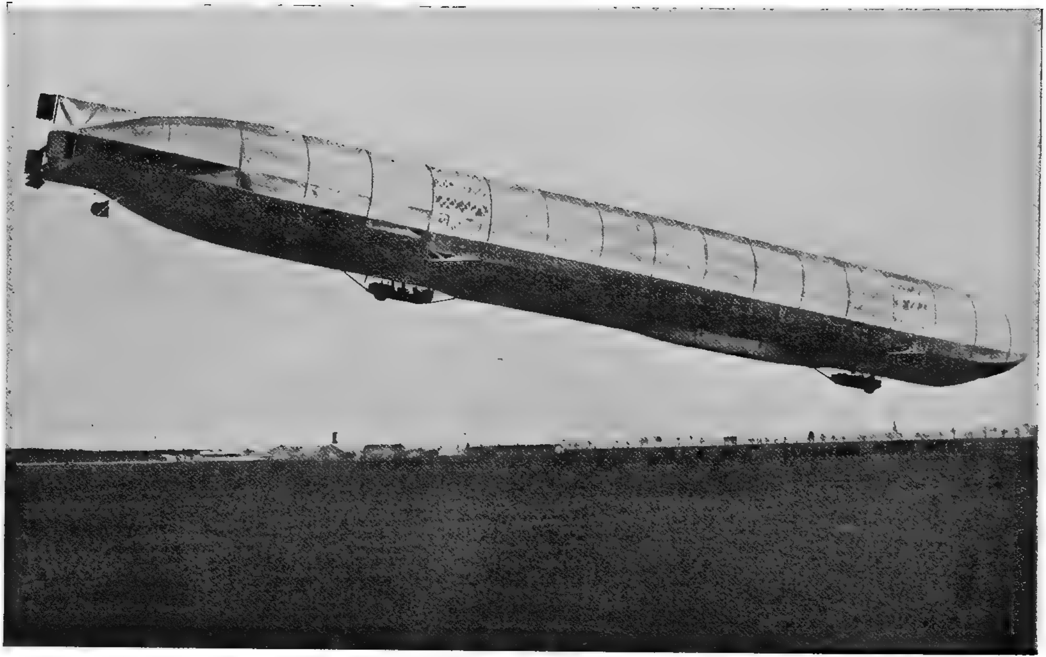
The level was maintained by a weight, sliding along a rail. This could be used to elevate or depress the nose so that the airship could ascend or descend without losing gas, though this was only attempted at a very small angle. Below the framework was a triangular keel, broken at two points to allow of two cars shaped like boats being suspended. In each car was a 16 horse-power engine driving a screw propeller.

The first ascent of this monster was made in July, 1900, and was a failure. The speed was only 8½ miles an hour, the steering ropes got tangled, and the airship was injured when returning to its floating shed on Lake Constance. Three months later another ascent was made. On this occasion a speed of 20 miles an hour was attained—faster than that of any previous airship, and five years before an aeroplane had been propelled by an engine for more than a few yards.

Let us pause for a moment to realise the money and labour of making a great airship of this kind. Think of the great aluminium framework 140 yards long, and nearly 13 yards in diameter. If this alone were lowered into many a street it would fill it from end to end, from side to side, and from the level of the road to the tops of the houses. Try to imagine the number of aluminium rods, and the screws, bolts, and rivets required to fasten them together. Then consider the number of yards of linen required to cover the 50,000 square feet of surface, besides the silk required for the sixteen gas ballonnets, each large enough to raise a man in an ordinary balloon. When you have all these facts before you it is easy to understand the enthusiasm which greeted Zeppelin's success, and which led the Government to give him the assistance he required for further experiments. You will not be surprised to learn that the cost of such a vessel was nearly £25,000.

Six years after his first triumph Zeppelin II was ready. This made a successful trial trip, but was destroyed the following night by a gale. Within a year, a new one was ready, and made a famous voyage of 69 miles with eleven passengers. The fourth vessel was launched on the aerial sea in 1908, and, after making a voyage of 21 hours' duration, was destroyed by fire.

The repeated successes and disasters excited the



THE ZEPPELIN "HANSA" LEAVING THE AERODROME IN THE NEIGHBOURHOOD
OF BERLIN DURING THE GREAT WAR.

admiration and sympathy of the German nation, and a fund of £300,000 was raised to help him to continue his work. The result was Zeppelin V, which was handed over to the War Department, and a passenger airship which made a voyage of 150 miles with twenty-six passengers. The next year a voyage of 900 miles was undertaken, the vessel remaining aloft for 38 hours.

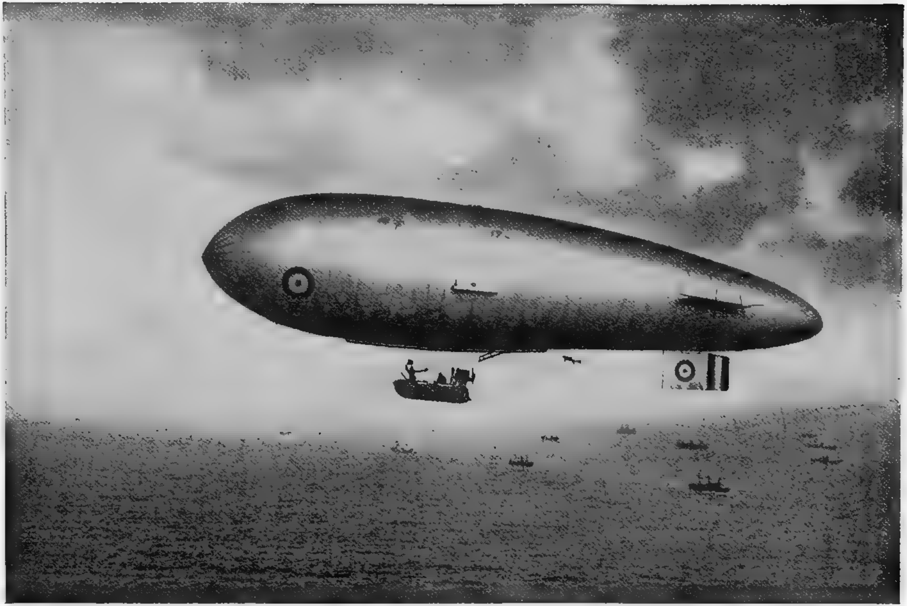
And so the struggle has been continued. Airship after airship has been lost—often with the lives of the men who manned them. But fresh ships have been built, increasing constantly in size and speed and carrying power. The largest aerial " liners " built before the War were about 550 feet long, 50 feet in diameter, and attained a speed of 30 miles an hour. One was used on a regular service, making 183 journeys and carrying over 4,000 passengers in the course of seven months. But their lightness and enormous surface give the wind a terrible hold upon them, and they are more helpless in a storm than is a ship at sea.

CHAPTER XXIII.

Airships of To-day.

During the War all kinds of airships were tremendously improved. Great Britain developed non-rigid ships, in which she had the most experience, Italy constructed enormous aerial vessels of the semi-rigid type, and Germany continued to improve her Zeppelins.

In August, 1914, Great Britain had only four small airships available against Germany's fleet of nearly twenty Zeppelins. A large rigid ship of the Zeppelin type had been built for the British Admiralty in 1911, and was called humorously the "Mayfly," but it



By permission of *The Air Ministry.*

NON-RIGID AIRSHIP OF S.S. ZERO CLASS USED FOR SUBMARINE HUNTING AND CONVOY ESCORTING. AN OBSERVER IS SEEN SIGNALLING TO THE CONVOY.

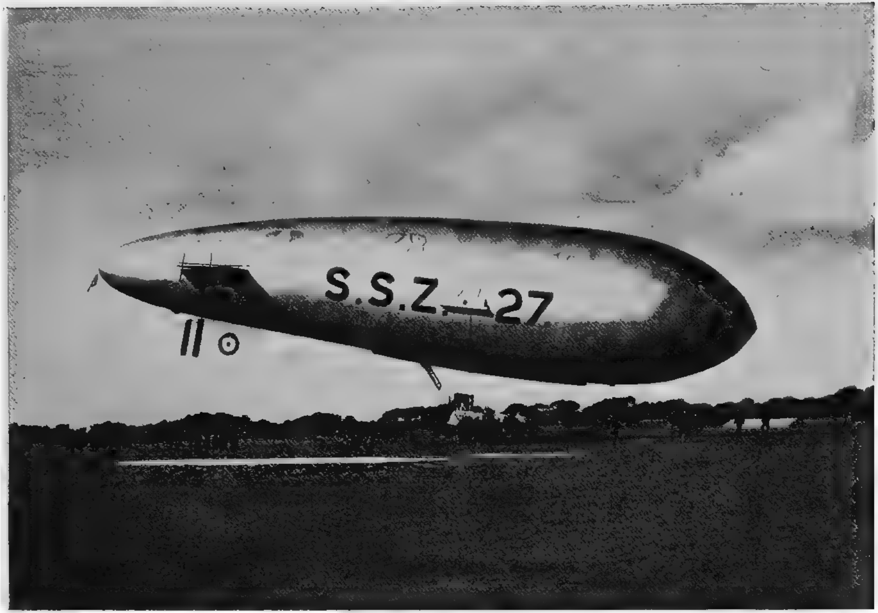
unfortunately broke its back when leaving the shed in which it had been built.

A non-rigid airship has a simple bag which collapses when empty. The front end, or nose, is rounded, and the tail, which tapers to a point, has " fins " which are used as rudders. The car is suspended from the envelope and great difficulty was experienced in the early days in arranging the suspensions in such a way that they did not pull the envelope out of shape.

It was the submarine menace early in 1915 that first aroused British activity in airship construction, and an experiment was made by slinging the fuselage of an aeroplane to an envelope of 20,000 cubic feet capacity belonging to an airship previously purchased from Mr. Willows, who had built several between 1905 and 1914. This was so satisfactory that a number more were constructed, having a capacity of 60,000 cubic feet. They were called submarine scouts, and labelled " S.S." with a number. At the end of the war we had no fewer than 150 of this class of airship.

The envelope of the " S.S." ships was of the same form as the Astra-Torres, an airship built by the Astra Company in France. It was not circular in section, but had three lobes, an arrangement which rendered easier the attachment of the car. The total length was 143 feet 6 inches, and the maximum diameter 27 feet 9 inches. There were two ballonnets—one fore and one aft—each of 6,375 cubic feet capacity. The original method of keeping these full of air by means of a pump had not been found satisfactory, and they were charged from a sort of funnel, placed just behind the propeller to catch the back-rush of air.

The crew consisted of a pilot and observer, and as there was only sitting accommodation no sleep was possible



By permission of *The Air Ministry.*

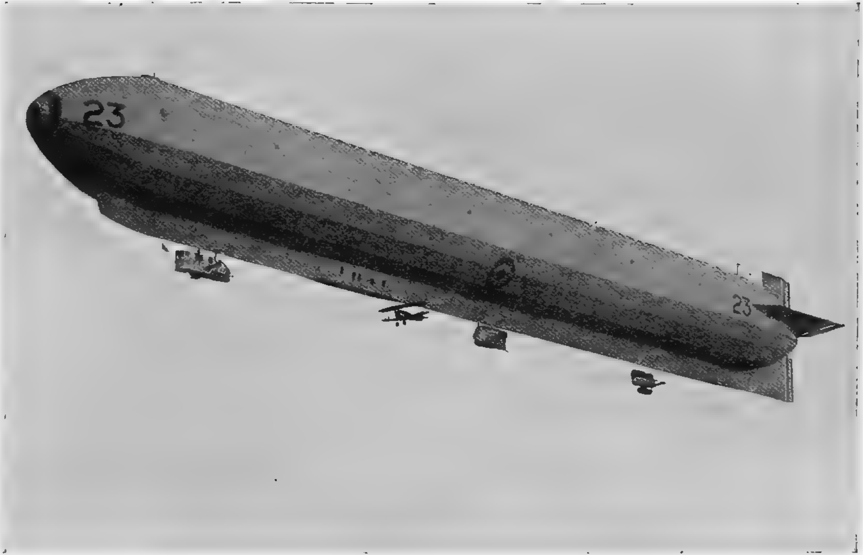
NON-RIGID AIRSHIP, S.S. ZERO TYPE, IN THE HANDS OF A LANDING PARTY.

for either of them. At cruising speed, which is most economical of petrol and oil, the airship could remain in the air for sixteen hours. The full speed was about 40 miles an hour. A 75 horse-power engine drove a four-bladed propeller, and a wireless telegraph outfit enabled signals to be sent or received from a distance of 50 miles.

The " S.S." Zero was an improvement on the type. It had a capacity of 70,000 cubic feet, was more comfortable, and could remain in the air for a longer time—in fact, one remained in the air for more than fifty hours.

The success of the " S.S." type encouraged designers to attempt larger ships which would remain in the air for longer periods, and be capable of patrolling long stretches of coast or escorting ships long before they reached port. They were called the " Coastal " and " C Star " type, and each ship as it was built was given a number. The envelope of the " Coastal " ships has a capacity of 170,000 cubic feet, and of the " C Star " a capacity of 210,000 cubic feet. The former carried two engines of 220 and 100 horse-power, and the latter two of 260 and 100 horse-power, and one of the Coastal ships flew altogether over 66,000 miles in two years and two and a half months. Though no sleeping accommodation was provided, ships were on many occasions in the air for more than twenty-four hours.

But they were not big enough for the wider patrol which was necessary to combat the submarines, and after 1916 the " North Sea " class was built. The capacity of the envelopes of these ships is 360,000 feet, or six times more than those designed a year earlier. The car, which carries ten men, is enclosed, and provided with windows and portholes, and the aluminium tanks containing the petrol are placed inside the envelope. Two 250



By permission of The Air Ministry.

R23, ONE OF THE EARLIEST RIGID AIRSHIPS BUILT BY THE BRITISH FOR SERVICE DURING THE GREAT WAR. AN AEROPLANE IS SUSPENDED FROM THE KEEL AND RELEASED DURING FLIGHT.

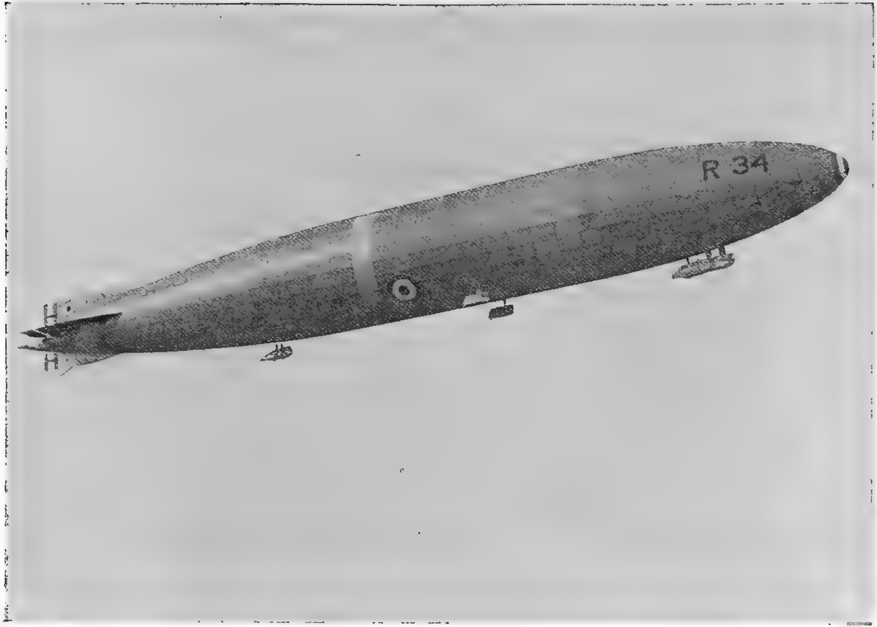
horse-power engines are used, and the ships can remain in the air for thirty to fifty hours.

These non-rigid airships have no equals in their class. They are the largest and most successful of their type in the world. Neither Germany nor Italy, nor France, nor the United States possess anything like them. In fact, the Italians devoted all their attention to the semi-rigid type, in which the envelope is attached to a long rigid keel. Moreover, whereas the British and German airships were required to operate over the sea at relatively low altitudes and in the teeth of stormy winds, the Italians required theirs to operate over the land. They had to ascend to a great height to be out of range of gun fire, and at these altitudes the winds are relatively light and storms rare.

Germany, on the other hand, had continued to improve the rigid airships of the Zeppelin type, and in 1914 the British had one only in course of construction. This ship, called " R9," was completed in 1917, and was used to train crews for later ships. Other ships were constructed, but as the only information which British designers had related to the Zeppelins built before the war, they were not equal to the more recent German ships.

However, the German secrets could not be kept for ever, and on 24th Sept., 1916, the L33 was damaged and forced to land in Essex. Though the crew set fire to the vessel, a great deal of information was obtained from the wreckage ; and this, together with the experience already gained, enabled " R33 " and " R34 " to be built.

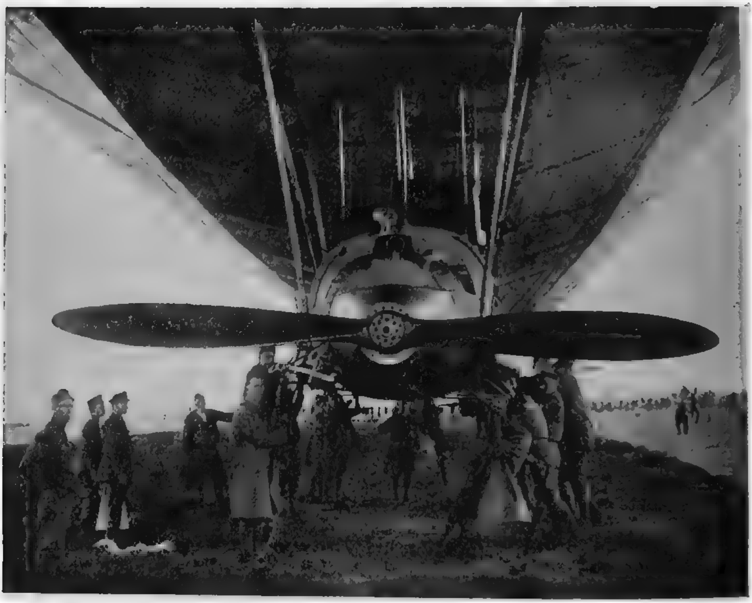
The modern rigid airship has a long cigar-shaped body, constructed of duralumin, an alloy of aluminium, at least two and a half times stronger than aluminium itself. The body is 643 feet long, 79 feet in diameter, and is



By permission of *The Air Ministry.*

R34, THE FIRST AIRSHIP TO FLY ACROSS THE ATLANTIC FROM ENGLAND TO AMERICA AND BACK AGAIN.

covered with fabric. It is divided into nineteen compartments for the gas bags, and there is an internal keel, which forms a means of communication between the cars. The cars are four in number. The forward car contains the navigating room, the wireless cabin, and the forward engine room ; then follow, amidships, two wing cars with engines ; and further aft is another car with two engines. The ship can carry a load, including petrol and the crew, of about twenty-six tons. Both ships were completed and carried out their trials successfully early in 1918,



VIEW SHOWING ONE OF THE LARGE PROPELLERS OF R34, WHICH IS BEING ASSISTED BY AMERICAN SOLDIERS WHEN LANDING IN AMERICA.

and in June the " R34 " made a flight of fifty-six hours' duration over the Baltic and along the north coast of Germany.

This ship will always be remembered as the first airship to cross the Altantic. With thirty men on board she left her mooring ground early in the morning on 2nd July, 1918, and arrived at Mineola, New York, on the morning of 6th July. Beginning her return voyage on 9th July, she reached Rilham, in Norfolk, on 13th July. The outward journey took 108 hours 12 minutes, and the homeward journey only 75 hours 3 minutes. Neither was free from anxiety. On the outward voyage fog was encountered near the Newfoundland coast, the course had to be altered to avoid electrical storms, head winds were encountered, and there were fears that the petrol would run short. Again, on the second day after leaving Mineola, one of the engines broke down and could not be used again.

CHAPTER XXIV.

Liquid Air.

About twenty years ago the newspapers, and, more especially, the popular magazines, used to contain frequent references to liquid air, and in many parts of the country lectures were delivered, and experiments performed with it. For, after well-nigh a hundred years of constant struggle, man had succeeded in converting all known gases to their liquid form. During that time money had been spent freely, and whole lives had been devoted to the problem. Now and again a partial success was achieved, and the man who did it was hailed as a victor ; but his success was not enough to satisfy either him or others, and they still worked on.

When man seeks to explore new fields of knowledge, there are unknown perils to be faced, and perhaps this adds zest to the search. In the course of the experiments there was always danger, the force employed sometimes blowing to fragments apparatus that had taken years of thought to devise. Occasionally a man was injured, and one man was killed; but, all things being taken into account, accidents were rare, and the only kind of courage that was really tested was that which refuses to accept defeat.

Now, it is quite clear that the results of a hundred years of strenuous labour by many men cannot be described in a few words. Moreover, as the liquefaction of air was only part of the great task that scientific men had set themselves to achieve, it will be necessary, and not without interest, to refer to some matters in which air is not concerned.

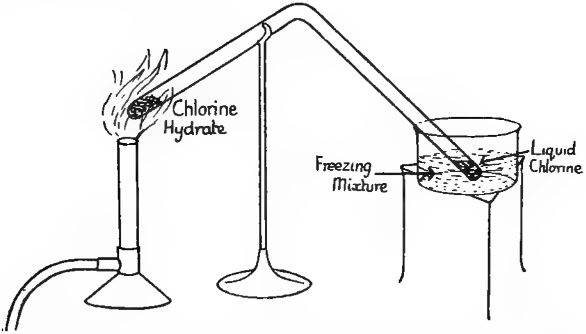
When a liquid is heated it passes off into a vapour, and when the vapour is heated it turns into a gas. If a vessel is filled with a vapour and the temperature is lowered, some of the vapour turns into liquid; but, if the vessel is filled with a gas, lowering of the temperature does not produce liquid. A vapour, therefore, is a gas near to the temperature of liquefaction. Having understood the meaning of these terms, let us proceed a step farther.

It was apparent to the scientific men who considered the question that, as a liquid at the ordinary temperature was converted into a gas on heating, a gas at the ordinary temperature might be converted into a liquid on cooling. But there was another way of looking at it. Since the change from liquid to gas was accompanied by a great increase in volume, it might be supposed that great pressure applied to a gas would squeeze it into the liquid condition. So that both cooling and increasing the pressure on the gas would be more effective than either method used alone.

One of the earliest attempts to liquefy gases was made by Michael Faraday, of whom you may have heard. He was the son of a blacksmith who lived at Newington Butts, now a part of London, and at an early age he was apprenticed to a bookseller and bookbinder. Gifted with a great thirst for knowledge, he eagerly read the volumes which passed through his hands, especially one by Mrs. Marcet, called *Conversations on Chemistry.* With the few pence he could save from his wages he bought some simple pieces of apparatus, and delighted in repeating for his own pleasure the experiments about which he had read. This practice he maintained all through life; he could never thoroughly understand an experiment by reading alone, and always repeated those of the men who had preceded him.

In those days, early in the nineteenth century, there were few opportunities for obtaining instruction. Science was rarely taught even in the Universities, and not at all in schools, which were few and far between. But at the Royal Institution in London there was a body of men who were adding daily to the knowledge of Nature, and giving frequent lectures in which they described the results of their investigations. Among them was Humphry Davy, who was making wonderful discoveries in chemistry.

When Faraday was about 17 years of age, a customer of his master, who had frequently noticed the young man's enthusiasm for science, gave him a ticket to four lectures by Davy. If you know what enthusiasm is, and what it means to struggle day after day in comparative poverty and in the face of great difficulties, you can imagine the joy that attendance at these lectures brought into Faraday's life. Do you think that for a single moment his eyes left the deft fingers of the lecturer as he performed his experiments, or that his ears missed a word that fell from his lips? The privilege was too great to be treated lightly, and it stiffened his determination to leave the bookshop and enter the laboratory at the first opportunity.



FARADAY'S APPARATUS FOR OBTAINING LIQUID CHLORINE.

(The chlorine hydrate only needs to be warmed gently.)

At the conclusion of the lecture Faraday wrote out full notes and sent them to Davy with a letter, expressing his desire to enter on a scientific career, and asking for advice. The result was an offer to take him into the laboratory of the Royal Institution as an assistant—an offer which was eagerly accepted. The young man was immediately in his element. In addition to assisting Davy he made discoveries on his own account, ultimately becoming a Professor in the Institution, and gaining a reputation greater even than that of his illustrious master.

In 1823 Faraday was examining the properties of chlorine, a yellowish, evil-smelling gas which had been obtained from common salt by the Swedish chemist, Scheele, and he found that, when passed into cold water, it formed yellow crystals. On heating these crystals chlorine gas was driven off, and water remained. It occurred to Faraday that this might be used to obtain liquid chlorine, so he placed some of the chlorine hydrate, as the crystals were called, at one end of a tube bent as in the figure. Heat was applied to the crystals while the other end of the tube was cooled. Soon yellowish-green oily drops began to form at the cool end, and at this point Dr. Bence Jones (who afterwards wrote a Life of Sir Humphry Davy) passed through the laboratory with Davy himself. Seeing the oily drops in the tube he thought it was dirty and reprimanded the young chemist for his untidiness. The next day he received a note as follows—

"Dear Dr. Bence Jones,

"The oily drops you saw in the tube to-day were liquid chlorine.

"Yours truly,

"MICHAEL FARADAY."

Thus was announced the first successful attempt to liquefy a gas.

Of course, Faraday was by no means sure what was going to happen, but he felt certain that the chlorine would be driven off on heating, and he hoped that the pressure would be sufficient to liquefy it. If liquid was formed it was sure to be found at the cooler end of the tube. But the tube might have burst, and the experiment was a dangerous one.

CHAPTER XXV.

How Cold is Produced.

You will wonder, perhaps, how Faraday cooled the end of the tube in which the chlorine condensed, and the answer is a very simple one. He used a mixture of ice and common salt. But if you want an explanation it will be necessary to consider the relation between solid, liquid, and gas again. If a liquid is heated it tends to become a gas; if you cool a gas it tends to become a liquid. The gaseous state, therefore, requires heat, and, if you convert a liquid into a vapour or gas without applying heat to it, heat is absorbed from anything else in the neighbourhood.

Recall for a moment the old experiment of finding which way the wind blows when the breeze is so light that it can hardly be felt in the ordinary way. A wet finger, held up, immediately becomes cold on the windward side. The air passing over the surface takes up the moisture as invisible vapour, and every particle of water that disappears in this way takes a certain amount of heat with it. The more quickly a liquid evaporates the more rapidly is heat lost from the remainder, from the vessel in which it is contained, from the air, and from any surrounding objects near enough to be affected. Thus, methylated spirit, or, still better, ether, evaporates more rapidly than water, and the cold produced by it is more intense.

Ether is a highly inflammable liquid that readily gives off vapour. If care is not taken this vapour may spread some distance, and cause a dangerous fire, but if there are no lights or fires about some very instructive experiments can be performed with its aid. One is to pour a little into a small beaker or metal can standing on a wet wooden block, and then to blow air through it by means of a pair of bellows. The air carries away ether vapour from the liquid, which cools rapidly, so that at the end of a minute or two the beaker or can is found to be frozen hard to the wood block. If a small tube of water be immersed in ether through which air is blown, the water will rapidly be converted into ice.

This absorption of heat always accompanies an increase in volume. If the gas expands rapidly the gas and the vessel containing it are cooled. On the other hand, if the gas is compressed heat is, as it were, squeezed out of it, and both the gas and the containing vessel become hotter than they were before. This furnishes a simple method of producing cold; for if a gas is compressed the heat at first formed will soon flow away, and cold can be produced by allowing the gas to expand. But before we proceed to see how that is utilised let us consider the relations of the solid and liquid conditions.

When heat is applied to a solid it changes into a liquid—in a very few cases directly into a gas. There is not much difference here in the volume, but there is a vast difference in the properties. A solid can be cut into various shapes and, when once cut, will remain in its new shape for an indefinite period; but the particles of a liquid slide so easily over one another that the liquid takes the shape of any vessel into which it is placed, and the free surface is always horizontal.

Now, just as a certain amount of heat is necessary to transform a given weight of liquid into vapour, so a definite amount of heat is required to convert a given weight of solid into liquid. This heat is again given out when the liquid turns back into the solid. If, therefore, a solid is suddenly liquefied, heat is required, and if no heat is supplied it will be taken from surrounding objects, which consequently become cooler.

Long before Faraday's time it was known that if water contained a dissolved substance it required a lower temperature to freeze it, so that a mixture of ice and salt even below the ordinary freezing point really ought to be liquid. Probably you have noticed how ice and snow are cleared from the streets by scattering salt upon them. The ice is melted, and the temperature falls to that at which a solution of the same composition would become solid. Such a mixture was used by Faraday nearly 100 years ago to aid in the liquefaction of chlorine. It is used to-day to make ice-cream. A solution of common salt or a similar substance is also used to cool the chambers in which food is preserved in cold-stores; to cool the holds of steamers in which meat is brought to this country from Australia, New Zealand, and Argentine; and for a hundred other purposes which cannot be dealt with in this little book.

The lowest temperature that can be produced by ice and salt is obtained with a mixture containing 23·5 per cent of salt, and is 0° F. A still lower temperature can be obtained with ice and calcium chloride.

The temperature that can be obtained by evaporating a liquid depends upon two things—the temperature at the commencement, and the rate at which it can be forced to evaporate. As every ounce of the vapour takes away a definite amount of heat, the lower the temperature at the beginning the lower will be the point reached.

In the case of the expansion of a gas, again, there are two conditions. The amount of increase in volume is a measure of the heat absorbed, and if the temperature is low to begin with, the final temperature for a given expansion will also be low.

It is important to remember that heat always flows from hot bodies to cold ones, and that in producing cold it is necessary to surround the vessel that is being cooled with material that offers a great resistance to the passage of heat. On this account a quick experiment enables a lower temperature to be obtained than a slow one, because there is less time for heat to leak in from outside. The lower the temperature that is obtained the more difficult it is to keep heat out, and that is why progress in our knowledge of low temperatures has been so slow.

There is one very interesting experiment with which every one ought to be familiar. The illustration will explain what a *cryophorus*, invented by Wollaston, is like. It consists of a tube with a bulb at each end, bent so that one hangs downwards by a short neck. All the air has been pumped out so that there is nothing but water in one bulb, and water vapour in the rest of the apparatus. If this is placed with the lower bulb in a freezing mixture the water vapour in it is condensed. More vapour comes off from the water in the upper bulb to take its place, and as this vapour takes away heat the water cools until at last crystals of ice form on the surface. The water freezes, therefore, by its own evaporation.

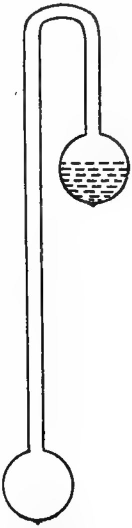


DIAGRAM OF A CRYOPHORUS

CHAPTER XXVI.

Mastery at Last.

For some years after Faraday's experiments no one appears to have made any great progress, but men were still busy, and Thilorier succeeded in liquefying carbon dioxide. This gas is, as you know, exhaled by men and animals, the oxygen of the air combining with the carbon in the waste material of the body. It is also produced when coal, wood, or any other substance containing carbon is burned in the air. But for experimental purposes the best way to make it is to act upon limestone or marble with an acid. Thilorier's apparatus consisted of a strong iron bottle mounted on "trunnions" or pivots so that it could be turned completely upside down. This was charged with lumps of marble, and a tube inside was filled with an acid. The cap, from which strong narrow tubes led to another similar bottle, was then screwed on and the bottle was turned over. The acid ran out of the tube and attacked the limestone, and the gas which came off was liquefied in the other bottle by its own pressure. As the pressure required to liquefy carbon dioxide at a temperature of 13° C. is about 735 lb. on the square inch, the experiment was not without danger. Indeed, on one occasion, when the liquid was being prepared for a lecture in Paris, a bottle did explode. The fragments of cast iron were flung in all directions with great violence, and an assistant was killed.

If liquid carbon dioxide is allowed to escape, it instantly changes into gas and becomes very much cooled—so much so, in fact, that some of it is converted into the solid. The simplest way of collecting this solid is to hold a canvas bag over the mouth of the tube from which the gas is escaping, when it is rapidly filled with a snow-like solid. This requires careful handling. It can be rolled up into a ball, but if it comes into close contact with the skin a blister is formed ; when it is held in the hand lightly, however, the gas which is continually produced forms a kind of cushion upon which it rests.

Probably you have read before that very cold bodies have much the same effect upon the skin as very hot bodies. That is one reason why men in the arctic or antarctic regions always wear gloves ; any attempt to hold a rifle, for example, in gloveless hands would result in dangerous sores. With carbon dioxide snow there is not much danger, because, as a rule, one does not pinch it so tightly as would be necessary with a heavy object, and it can be dropped quickly when it begins to " bite."

We have no space to describe here the interesting experiments that can be performed with this substance. Its interest for us lies chiefly in the fact that, when mixed with ether, it produced the greatest cold that was obtainable for many years. The temperature falls to—80° C., or 80° C. below the freezing-point of water. In this degree of cold, mercury, which is used in thermometers and barometers, is frozen solid. If the gas and vapour are pumped away rapidly, the temperature falls 20° C. lower still, and hardly any substances that are liquid at ordinary temperatures remain fluid. They shrink more and more, and at last become solids.

During the greater part of the nineteenth century, carbon dioxide and ether were used very largely for producing cold, and with the aid of high pressures many gases were liquefied. But oxygen, nitrogen, and hydrogen resisted all the earlier attempts. Scientific men, however, were getting to know more about the subject, and in 1868 Dr. Andrews of Dublin made a discovery that suggested why some attempts had failed. He found that, unless carbon dioxide was at a temperature lower than 31° C., no amount of pressure would liquefy it. This temperature is called the *critical* temperature. The pressure required to liquefy the gas at that temperature is called the *critical* pressure, and the volume that it occupies at the moment of liquefaction is called the *critical* volume.

What is true of carbon dioxide is true of all other gases. For each one there is a certain temperature to which it must be reduced before the most powerful pump in the world will liquefy it. Up to this time, men had not understood the problem, but had thought that *either* cold or pressure would serve the purpose. They now realized that cooling to some extent was absolutely necessary, and, only if a low enough temperature was reached, would pressure do the rest.

The difficulty in the case of oxygen, nitrogen, and hydrogen was to cool the gas below the critical temperature. It was done ultimately in the case of oxygen by a Swiss and by a French engineer who worked independently of one another. M. Raoul Pictet, of Geneva, was the first to publish his results, but M. Cailletet, the French mining engineer, had completed his experiments a month or two before, and had deposited a written statement of his success with the Secretary of the Academy of Sciences at Paris. When great discoveries are made there is often keen rivalry between men for the credit of being the first to achieve success, and there is often a great deal of ill-feeling. But in this case it is quite certain that each man was ignorant of the work of the other, and, though Cailletet was first, the honour must be shared between them.

Cailletet's method was to compress the gas in a strong metal cylinder, at one end of which was a strong, narrow glass tube. The space in which the gas was confined could be enlarged very considerably and very suddenly by unscrewing a plug. But the rapid expansion of the gas cooled it, and a mist appeared in the glass tube. This mist must have been caused by drops of liquid oxygen.

Now consider Pictet's method. He also compressed the gas into a strong vessel, but caused it to pass through a pipe which was specially cooled. Carbon dioxide was first compressed, and liquefied by being allowed to flow through a pipe surrounded by liquid sulphur dioxide—a gas that liquefies rather easily. As the liquid sulphur dioxide boiled away it took heat from the carbon dioxide in the inner pipe and caused that to liquefy. Then the liquid carbon dioxide was passed round another pipe into which the oxygen was compressed. When a tap in the end of this tube was opened a stream of liquid oxygen escaped, but it flashed off into gas almost as soon as formed.

Though both Cailletet and Pictet had succeeded in obtaining liquid oxygen, neither of them had succeeded in collecting any. In 1877 the world knew that the liquefaction of oxygen was not impossible, but another eighteen years were to pass before this wonderful liquid could be obtained in quantity and examined at leisure. A great many wonderful experiments were carried out by two Poles named Wroblewski and Olzscewski, by Dr. William Hampson and Professor James Dewar in England, by Dr. Carl Linde in Berlin, and by Charles Tripler in America. But it would take too long to describe their methods, their failures, and their successes.

Let us look rather at an experiment that enables liquid air or any other gas to be produced in quantity and sold as a regular commercial article. Lord Kelvin and Dr. James Prescot Joule found that, when a gas was forced through a very fine hole or a porous plug (which contains a number of fine holes) it cooled. For a given difference of pressure at each end of the hole there is a definite fall of temperature. If the difference of pressure is 15 lb. on the square inch, the fall of temperature will be about 0·25° C. ; for 60 lb. on the square inch the difference will be 1°C. ; for 600 lb. on the square inch the difference will be 10° C. ; and so on. Now, if the gas which has been cooled in this way flows back round the gas which is approaching the hole, this latter gas will be cooled, and the gas that enters the hole or plug will be lower by 10° than the first lot that was passed through. In this way, pumping the gas round and round causes it to fall in temperature until ultimately not gas but liquid issues from the hole.

If you reflect upon this process you will see that it goes on continuously so long as the pump is kept working. The particles of the gas are pressed closer and closer together so that when they pass through the cooled tube they shrink together into the liquid form. In this way oxygen, nitrogen, and hydrogen have been liquefied, and, of course, air as well. The process is used, not merely in scientific laboratories, but in huge factories, and it has an important bearing on the food supply of the world. But, first, let us see what liquid air is like, and how it is kept.

Liquid air is a clear colourless liquid that looks as though it might be water. If a little is poured into a glass tube the moisture in the air condenses on the outside into hoar frost. Mercury in a tube dipped into the liquid is frozen almost instantly into a solid rod, which can be beaten with a hammer as if it were lead.

An iron nail, which at ordinary temperatures can be bent, becomes so brittle after immersion that it can be broken by a blow of a hammer. Feathers, india-rubber, and other soft things become hard. If you blow a soap bubble on the end of a glass rod and hold it over the surface of the liquid, it is frozen solid, and when struck on the table shivers into fragments. Some of the liquid poured into the boiler of a model engine causes it to work vigorously, while quickly becoming encased in ice.

The credit for finding a method of collecting and keeping this intensely cold yet powerfully energetic liquid belongs to Professor James Dewar. The problem was to construct a vessel that would allow the warmth of the surrounding air to pass through it as slowly as possible. Now, there are three ways in which heat passes from one body to another. One is from particle to particle of a solid, liquid, or gas, each particle receiving heat from the one behind, and handing it on to the one in front. This is called *conduction*. Another way, which occurs only in gases and liquids, is by the actual movement of the material. This is called *convection*. The third method is one in which heat is passed across space quite independently of the matter which fills it. By this means the heat of the sun reaches the earth during the day, and the warm earth becomes colder during the night. The process is called *radiation*.

The best way to prevent loss of heat by radiation is to have a brightly silvered surface. You probably know that tea keeps hotter in a silver teapot than in one that is dull; and, if so, you will not be surprised to hear that a silvered surface is the best for a vessel meant to contain liquid air. But Professor Dewar's important discovery was that if the air was pumped out of a vessel the space offered more resistance to the passage of heat by conduction and convection. He made, therefore, flasks with double walls, from the space between which all the air had been pumped so that the inner vessel was surrounded by a vacuum. They are called " vacuum flasks," and liquid oxygen can be kept in them for many hours if the mouth is lightly plugged with cotton wool.

Of course, such flasks will retain heat just as well as they will exclude heat, and they are used as " thermos flasks " for keeping liquids hot. Coffee or soup will remain hot in such flasks for twenty-four hours ; they are much used by travellers and others who have to make long journeys. The glass is enclosed in a metal case, covered with leather to prevent breakages, and the cap forms a drinking cup.

The fragile glass vessel, which would be shattered by a fall, is enabled by this discovery to hold a quantity of liquid in which enormous power lies concealed—in very truth a tame whirlwind. But tame only so long as it is not confined too closely. The tiny particles which form the innocent-looking liquid have been all round the world ; if they could speak, what a tale they could unfold ! They have whistled round the poles, and been wafted across the equator. They have expanded beneath the tropical sun, and have shrunk closer together under the influence of the icy cold of the arctic and antarctic regions. They have raged through forests, torn up trees, and destroyed peaceful towns in cyclonic fury ; they have lashed the ocean to anger and driven great ships upon rockbound coasts.

Is there anything to indicate the terrible force which this liquid can exert ? Nothing, unless a bubble now and then escapes and sends a tremor across its surface. Slowly, steadily it passes into a gas with hardly a sign, and it is only if you try to hold back the particles that have gained their freedom that there is danger. A continuous stream of invisible particles threads its way through the cotton wool in the neck and mingles with the atmosphere above, cooling it, and being warmed by it in its turn.

But you may ask, "Of what use is it? If large factories with powerful steam engines and huge pumps have been established to manufacture it, what object does it serve?" Well, in the first place, it is a source of oxygen, and oxygen is required for a number of purposes. Some is used to produce the oxy-acetylene flame, by means of which enormous slabs of metal are cut far more easily than by a saw or any other tool. There are now no shipyards, and very few engineering workshops, in which a blowpipe burning a mixture of oxygen and acetylene gas is not used. Then, again, it is used in cases of illness. When the lungs are diseased and the patient is very weak, he breathes so feebly that the air entering his lungs contains hardly sufficient oxygen to maintain the flickering spark of life. But, by allowing him to breathe a little oxygen, he secures what he needs with less effort, and human life is sometimes saved, and always prolonged, by its aid.

The oxygen is obtained from liquid air by a very simple device. The nitrogen boils at a slightly lower temperature than the oxygen, and comes off first, the liquid remaining behind becoming richer and richer in the latter gas. At first, the nitrogen, which carried over with it about 7 per cent of oxygen, was allowed to escape, but a use has been found for that. It is now passed through an electric furnace containing calcium carbide, by which it is absorbed. The substance formed is called nitrolim, and is valuable as a manure. Many thousands of tons are made annually in this way and sent to farmers all over the world. Norway, Switzerland, Italy, Germany, the United States, and Canada have large works devoted to the production of this artificial fertiliser, which enables man to wring from the exhausted soil a larger crop and a greater return for his labour. In the various processes of the farm, the nitrogen in the manure gets back into the atmosphere, but it cannot escape entirely. Sooner or later the wind wafts it within reach of the pumps which liquefy it with its companion oxygen. And then when it boils off it is again caught and forced into the electric furnace, to be imprisoned for the farmer's use, and to supply the increasing population of the world with food. When you remember also that the oxygen goes into the hospital, the steelworks, and the shipyard, you will realise that the experiments of Faraday, relatively unimportant in themselves, have gathered strength with the passing years, and are indirectly exercising not merely a useful, but a noble, service to mankind.

CHAPTER XXVII.

What is Air?

THE dictionary tells you that air is a mixture of gases, mainly oxygen and nitrogen, together wth minute quantities of three or four other gases. So far so good. If you have a clear idea of what a gas is, and if the properties of oxygen, nitrogen, and the other gases are known to you, the information will serve your purpose. But if you have not learned any physics or chemistry, you will not be much better off than you were before. A dictionary is very useful in its way, but it often gives so many meanings of a single word that it is not easy to see what the word really means. The fact is, a word varies in meaning according to the words with which it is associated in a sentence, and it is often better to try to get hold of the meaning of a sentence in which an unfamiliar word occurs before looking it up in the dictionary.

In this case we shall put the dictionary back on the shelf and try to find out what air is without it. First, however, let us settle this question of a gas. The stuff of which the world is composed—the earth and the sea and the air and all that therein is exists in the form of solid or liquid or gas. As a general rule, a solid can be converted into a liquid by heating it, and a liquid can be converted into a gas by the same process. Conversely, a gas may be converted into a liquid and then into a solid by cooling. This is true of many substances, though some undergo changes in the process which prevent the rule from holding good. Thus, many solids and liquids on being heated break up into other materials, some of which are solids, some liquids, and some gases. But as long as a substance remains the same throughout, the solid, liquid, and gaseous conditions depend merely on the temperature.

When a solid is converted into a liquid there is usually, though not always, an increase in its volume ; that is to say, the liquid takes up more space than the solid. Ice and some of the metals, however, *decrease* in volume on liquefying. But when a liquid is converted into a gas there is always an increase in volume, and this increase is very considerable. Steam, for example, takes up more than 1,600 times the space of the water from which it is produced.

The problem that presents itself is, What kind of structure must the stuff of the world have to allow of this great change of volume ? Is it like a jelly that gets thinner and thinner the larger the space it has to occupy? Consider for a moment a small quantity of a strong-smelling substance, such as musk, on the floor of a room. In a short time this will disappear, and can be detected by its scent in every corner of the room. There may not be a cubic inch of space in which some of it does not exist. Can you imagine this small quantity spreading upwards and outwards in a continuous jelly-like mass until it stretches from floor to ceiling and from wall to wall?

Suppose, on the other hand, that the substance were composed of tiny particles that escaped, a few at a time, and penetrated between particles of air until they were evenly distributed in every part of the room. It might then be impossible to secure a fraction of a cubic inch of air that did not contain some of the strongly smelling substance. While this explanation would be easier to understand than the other, it requires that the particles should be very small. For if the room were only 10 feet long, 10 feet wide, and 10 feet high, there would be 1,728,000 cubic inches in it, and that number of particles would be required if there was to be only one in each cubic inch. Moreover, if we suppose the effect to be produced by a cubic inch of the highly-scented material, it would mean that there were 1,728,000 particles crowded in that small space. And though the sense of smell is far less delicate than the methods that are employed by the chemist, less than a cubic inch would be enough to scent a room of this size.

This power of almost infinite extension is possessed by all gases whether they have any smell or not. A very similar result is obtained when a solid dissolves in a liquid. If a piece of sugar or salt is placed in a vessel of water the solid gradually disappears from view, and the sugar or salt spreads upwards and outwards until it has penetrated to every portion of the liquid. The smallest measurable quantity will contain not only water but sugar or salt. The process of solution is, therefore, similar in many respects to that of evaporation. A study of both leads us to the conclusion that matter is not continuous, but is composed of separate particles that are squeezed closer together by pressure, and separate when the pressure is reduced.

Early scientific men were puzzled to account for the tendency of gases to expand. They knew that in the case of such lumps of matter as we can see and handle there is cohesion or force of attraction between the particles that form the matter, and if the same held true of the particles of a gas there could be no expansive force and therefore no pressure. If heat turns a solid, in which the particles are held together, into a gas, in which they repel one another, then heat must either convert an attractive force into one of repulsion, or else create a repulsive force which overcomes that of attraction. How then can repulsion in the particles of a gas be explained ?

Suppose that the particles of which matter—solid, liquid, and gas—is composed are in more or less rapid motion, moving for short distances in straight lines, but continually colliding with one another ; and suppose that the effect of heat upon these particles is simply to increase their speed. In the solid condition, which is the result of taking heat away from a gas or liquid, the movements of the particles are sluggish. No particle is able to break away entirely from the attractive influence of its neighbours. If the particles are not all moving with the same velocity, one or two will escape occasionally, and this will explain why a little vapour comes off from many solids. But, in the main, the particles are held more or less firmly together, and their freedom of movement is very, very small.

In the liquid condition, which is produced by supplying heat to the solid, the particles are more lively. They move at greater speeds, so that they are more independent of and glide easily round one another. Moreover, a good many of them have a sufficiently high velocity to break away entirely when they come to the surface. This explains why vapour is always formed from the surfaces of a liquid; and it also explains several other things. If the effect of heat is to increase the speed of the particles, then if the more rapidly moving particles escape the liquid must be the cooler by their loss. There is, therefore, a reason why evaporation should always be accompanied by cooling.

Several examples of cooling by evaporation were given in Chapter XXV, and you will remember that this is a means of attaining very low temperatures. But the process is just the same under ordinary conditions, and when you hold a wet hand up to the wind the cold you feel is due to the escape of the more active particles of moisture.

If a drop of water, or other liquid that easily passes into gas, is introduced above the column of mercury in a barometer, it evaporates, and the mercury column falls. In a vacuum the livelier particles escape more easily, the whole drop flashes into vapour, the walls of the tube and the surface of the mercury are bombarded, and thus the effect of pressure is produced.

If more liquid is introduced evaporation goes on more slowly, until at last a layer of liquid remains on the top of the mercury. The column falls with each addition until, when evaporation ceases and some liquid remains, it becomes constant. The fall of the column is a measure of the *vapour-pressure* of the liquid at the temperature of the experiment. It represents the tendency of the liquid to pass into vapour, and is always the same for the same liquid at the same temperature. If the temperature is raised until the vapour pressure is equal to the atmospheric pressure, then the boiling point of the liquid has been reached.

The particles of a body are called its *molecules* ; the pressure of a gas is due to the bombardment of these molecules on the walls of the containing vessel. We do not know that this is a true picture of a gas in the sense that we can say a house is made up of separate bricks or stones, because the molecules are far smaller than anything we can see even with the aid of the microscope. If you can imagine a number of them placed side by side in a row there would be about 250,000,000 of them in an inch. How this has been discovered it would take too long to tell here, but the measurement has been made by more than one method. And a great many facts can be explained if a gas has actually the kind of structure that has been outlined.

This is all very wonderful, but if you read more advanced scientific books you will find that there are particles 1,000 times smaller than those we have described, and that the delicate methods of modern science enable these also to be measured and weighed. It is well, however, to remember that these are not matters of interest only to the scientific man in his laboratory, but to every one who at every breath fills his lungs with these lively molecules. And that reminds us that we have not said any anything yet about the relation of these particles to life.

CHAPTER XXVIII.

The Breath of Life.

It was stated at the beginning of the last chapter that air consists, in the main, of two gases—oxygen and nitrogen. More than 150 years ago, it was discovered that these two gases differed very much from one another. Metals and other substances, when heated in air, took up the oxygen and left behind a gas that would not support burning, and in which small animals died. The nitrogen was found to be one of the least active—at that time *the* least active—of all known substances, and its presence in air merely served to reduce the activities of its companion.

When a person takes a breath, he expands his chest, relieves the external pressure on the lungs, and allows air to enter these organs through the mouth and nose. The lungs consist of two bags filled with innumerable fine passages, the walls of which are very thin and well supplied with blood vessels. As the blood is pumped by the heart, into and through all parts of the body, it collects the waste material there and conveys it in a dark red stream back to the heart, from which it is pumped into the lungs. There the waste material is attacked by the oxygen of the air that has been breathed, and converted into carbon dioxide and water. The blood that issues from the lungs is bright red in colour and returns to the heart to be used over again.

It would, perhaps, be equally correct to say that the blood takes up oxygen from the lungs, conveys it to all parts of the body, and removes waste material. In the absence of oxygen this waste material remains in the blood, and death occurs from suffocation. The essential fact is that the life of men and animals depends upon the conversion of oxygen into carbon dioxide, and without a sufficient supply of oxygen life cannot exist.

A man takes about thirty cubic inches of air at every breath, and as this occurs about fifteen times a minute, he requires 450 cubic inches in that time. Of this amount, about ninety cubic inches is oxygen.

If the percentage of this gas is lower than usual owing to the presence of impurities, he must either breathe faster or suffer from the shortage of supply. On a high mountain or up in a balloon ninety cubic inches weigh less than at the sea level, a fact that explains the difficulty which explorers and balloonists have met with in their travels. This effect is separate from the reduced pressure that causes bleeding from the nose and ears at high altitudes. The diver and those who work under increased pressure, could ordinarily obtain the oxygen they require by a smaller breath. On the other hand, the weight they carry and the effort of moving through water require great exertion, and this compensates to some extent the increase in the amount of oxygen per cubic inch of air.

The conversion of oxygen into carbon dioxide also occurs, as is explained in *The Mastery of Fire*, when substances containing carbon are burned ; and you may well ask how it is that the oxygen in the air has not been used up long ago. The proportion of the two gases in air is almost invariable. In 100 cubic inches of air there are, as nearly as possible, 79 cubic inches of oxygen, 21 cubic inches of nitrogen, and 0·04 cubic inches of carbon dioxide. Yet every fire, every man, woman, and child, every living creature is greedily absorbing oxygen, and pouring out carbon dioxide in its place.

The cause of this constancy is to be found in the vegetable kingdom. Plants inhale air through small openings, called *stomata,* on the under sides of the leaves. They absorb the carbon dioxide, using the carbon to build up the green colouring matter by which members of the plant world are everywhere known ; and they give up the oxygen which they do not require. In this way a fair balance is maintained, and both plants and animals are adapted to live together in the same atmosphere.

You will easily understand that the constant composition of which we have spoken requires a free circulation of air. A room, or even a large hall containing a number of people, may easily become overcharged with carbon dioxide and become very unwholesome in consequence. Some people are particularly sensitive to such conditions ; they suffer from headache, and the atmosphere is said to be poisonous. The unwholesomeness, however, is not caused by the carbon dioxide directly, but by the lack of sufficient oxygen. There is an old saying—almost as old as the hills—that two things cannot be in the same place at the same time ; and if there is an excess of carbon dioxide in the air of a room, there must be a deficiency of oxygen or nitrogen or both.

But carbon dioxide is not the only indirect cause of a lack of oxygen in these circumstances. The impurities carried by the blood contain hydrogen as well as carbon, and this combines with oxygen to form water vapour. The breath is always charged with moisture, and this takes up space just as carbon dioxide does. Moreover, it acts in another way. The temperature that can be borne with comfort depends upon the amount of moisture in the air. Some moisture is always given off from the body through the pores of the skin, and this escapes more readily into dry air than into air already containing much water vapour. The free passage of this moisture from the skin is essential to health ; if it is retarded we become hot and weary instead of cool and strong. A person who has been for long in a hot, close, moist atmosphere is therefore likely to take cold afterwards, because the body is weaker and more open to attack.

All this points to the tremendous importance of ventilation. The air of living rooms and public buildings requires to be renewed frequently in order that those who occupy them may not suffer from discomfort, and run the risk of disease. Some buildings are so constructed that it is extremely difficult to ventilate them ; and, even if this were not the case, it is often difficult to convince people of the necessity of fresh air. In these days when so many are engaged in sedentary occupations, the lack of bodily exercise creates a need for artificial warmth, and almost a dread of the open window.

In ordinary dwelling-houses the most effective means of ventilation is the chimney. The stream of hot gases, rising from the glowing coal, carries with it far more air than is necessary to feed the fire. Gas stoves, which are now so popular, and which have many advantages, are less effective in renewing the air of a room. Unfortunately the chimney is often stopped up in summer ; though windows and doors can then be thrown wide open.

Ventilation is perhaps more important in bedrooms than in rooms used by day, because they are closed up for a number of hours. But this is just where there is the greatest need of reform. There is hardly a day in the year in Great Britain when the window might not, with advantage, be left open all night. The bed ought not to be placed between window and door or chimney, because though fresh air is necessary, a draught playing on one part of the body is liable to give rise to colds.

The ventilation of large buildings is a really difficult problem, and one that requires skill and experience to solve. There are two systems in use, one in which the air is forced in, and one in which it is drawn out. In the latter case the force may be a natural one or it may be artificial.

The first system requires a fan which draws air through an opening in the wall in the lower part of the building, and forces it through a series of channels in the walls, from which it escapes into the rooms through gratings. If the building is in a town the air is first freed from dust, and it is usually warmed in winter by being passed over hot pipes before it starts on its journey round the building. The warmth of a room in which people are working renders the air lighter, and this lightness is increased by the moisture formed during breathing. The foul air, therefore, tends to rise towards the upper part of the room, and openings are provided in the walls or ceiling for its escape.

The second plan requires a fan to be placed in the upper portion of the room or building, and as the foul air is propelled outwards by the fan fresh air enters through doors, windows or specially constructed openings to take its place.

If a building consists of a few rooms simply arranged, the natural system is adopted. This is based on the fact that the warm moist air rises and openings in the ceiling are provided for its escape. The rate at which the air flows through such a building depends on the difference of temperature between the air inside and outside, and is therefore most effective, as it should be, on dry, cold days. On warm summer days full use can be made of the doors and windows.

One of the great drawbacks to ventilation in towns is the dirtiness of the air. A proportion of the tiny particles of smoke from the chimneys of many factories and countless private houses settles in the rooms through which the air circulates, and if this is changed every few hours a considerable amount accumulates in a week. On the other hand air in fairly rapid motion deposits the finer particles less readily than still air, so there is after all something to be gained even in cleanliness, by ventilation.

Fresh air is one of the few valuable things lying around of which every man, woman, and child can have his or her fill. The health and vigour of those who live in the open as compared with the pale and sickly town-dweller should convince us that on any and every occasion we should get as much fresh air as we can, and use all we know of the conditions which govern its circulation to cause it to play softly and continuously around our bodies.

If fresh air is so important and yet so difficult to secure in the surface of the earth, how much more difficult must it be in tunnels and deep mines. Even in tunnels driven from side to side through mountains it has been found no easy matter to renew the air, and in many of the longer ones the steam locomotive has had to give way before electric traction.

The problem is the oldest in mines, and the ventilation of a large mine calls for a large amount of foresight and ingenuity.

The original plan depended upon natural ventilation. The temperature underground is warmer in winter and cooler in summer than the atmosphere, so that on most days a mine consisting of a horizontal tunnel in the mountain side and a shaft at the end would have a current of air flowing through it. But when mines were sunk beneath the surface two shafts were used, and at the bottom of one a fire was lighted so that it served as a chimney and drew air through the workings. To-day the fire is replaced by a fan, which either draws air from or forces it into the workings. Down below, the air threads a way through the network of corridors, being prevented from taking short cuts by wooden doors or rubber curtains called brattice cloths; for it is most needed at the coal face, to sweep away the gas which escapes from the freshly broken surface.

Without a full and accurate knowledge of the properties of air, only a small fraction of the treasures which lie hidden in the earth's crust, could be obtained; the wonderful tube railways of London and New York could never have been constructed; and the great railways of the world would have been confined to the level plain. This knowledge renders easy and healthy many manufacturing processes which would otherwise be difficult and dangerous; it enables the state of the weather to be foretold, and shows how the navigator can often avoid the threatening storm; it has enabled men to carry on the operations of peace and war below the surface of water, or high above, borne on the wings of the wind. The dreams of poets and philosophers in past ages have become vital facts of everyday existence to those who live in the twentieth century. And all along the path of progress are the graves of the heroes who gave their lives that the human race might enjoy the fruits of their labour, their courage and their intellectual power.

Printed in Bath, England, by Sir Isaac Pitman & Sons, Ltd.
x—(925)